Sippican, Inc.

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R-2119

Expendable Conductivity, Temperature, and Depth System (XCTD) Development Program

FINAL REPORT

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Sippican Ocean Systems, Inc
Marion, MA 02738-0861

Prepared by

Richard W. Lancaster
Richard W. Lancaster
Project Engineer

XCTD Development Program

Final Report

1.0 INTRODUCTION

This report represents the Final Report under contract number N00014-82-0579 for the development of the Expendable Conductivity, Temperature, and Depth (XCTD) probe.

This report contains descriptive material representative of the XCTD system as it has evolved over the course of the program. No attempt has been made to chronicle the events, wrong turns, and failed approaches that inevitably occur in a development program. The details of the mechanical and electrical design may be gleaned from the XCTD drawing package previously sent to the Scientific Officer.

1.1 Program Objectives

It was the objective of the XCTD development program to develop and test an expendable instrument system capable of providing ocean salinity to an overall accuracy of 0.05 parts per thousand. Table 1.1 is a summary of the design goals that emerged from this requirement.

1.2 Conclusions

A workable XCTD system has emerged from the development work pursued to date. An XCTD probe subsystem design has been built and tested at sea that provides data from the surface to 1000 meters as required. A deck gear subsystem, with supporting host computer software has been demonstrated in the laboratory and at sea. The calibration techniques have been developed that permit accurate calibration of probes in prototype quantities.

2.0 XCTD SYSTEM DESCRIPTION

The XCTD System is intended to provide the oceanographer with a low cost and convenient method of acquiring temperature, salinity, density, and sound speed data. The quantities are calculated from primary data collected from the probe measurements of temperature, electrical conductivity, and depth (pressure). The calculations of primary ocean parameters are accomplished via the Practical Salinity Scale of 1978 (PSS-78) and the International Practical Temperature Scale of 1968 (IPTS-68).

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TABLE I

XCTD DESIGN GOALS

SYSTEM REQUIREMENTS
(ONR/SOSI Contract)

Produce a System Capable of Presenting Salinity vs. Depth to an Accuracy of 0.05 Parts per Thousand

Implied Performance Specifications

PARAMETER	REQUIRED ACCURACY	REQUIRED RANGE
Temperature	0.03 C	-2 to 36 C
Conductivity	0.03 mS/cm	20 to 75 mS/cm
Pressure (Depth)	2 %	0 to 1000 M

Environmental Specifications

None Specified

The XCTD System may be thought of as consisting of the following subsystems:

1. The expendable probe subsystem
2. The deck gear subsystem
   - The Sippican MK9 data acquisition system
   - The host computer and XCTD software
3. The XCTD probe calibration subsystem

2.1 XCTD System Physical Description

Figure 2.0 shows the XCTD at-sea configuration. The probe subsystem and the deck gear subsystem are explicitly shown. The at-factory calibration system completes the XCTD system.

2.1.1 Expendable Probe Subsystem

The expendable probe subsystem consists of the actual probe that descends through the water column to collect data and the ship board canister and spool to dereel wire as the research vessel moves forward over the ocean's surface. Spools at each end of the wire link dereel in order that tension on the wire may be kept below the wire breaking strength to assure a communications link for the entire 1000 meters of probe depth capability.

The expendable probe itself falls at 3.248 meters/second +/- 2%, driven by the mass of the nose weight. Pressure, required for the salinity calculation, is derived from the known fall rate and measuring the time since the probe was launched.

Sensors, calibration components, and electronics aboard the probe sense temperature and electrical conductivity of the water that flows through the conductivity cell, convert the resistance of the sensors to frequency, and drive the frequency along the BT wire to the deck gear subsystem. Figure 2.1 is a cut away view of the development model of the XCTD probe.

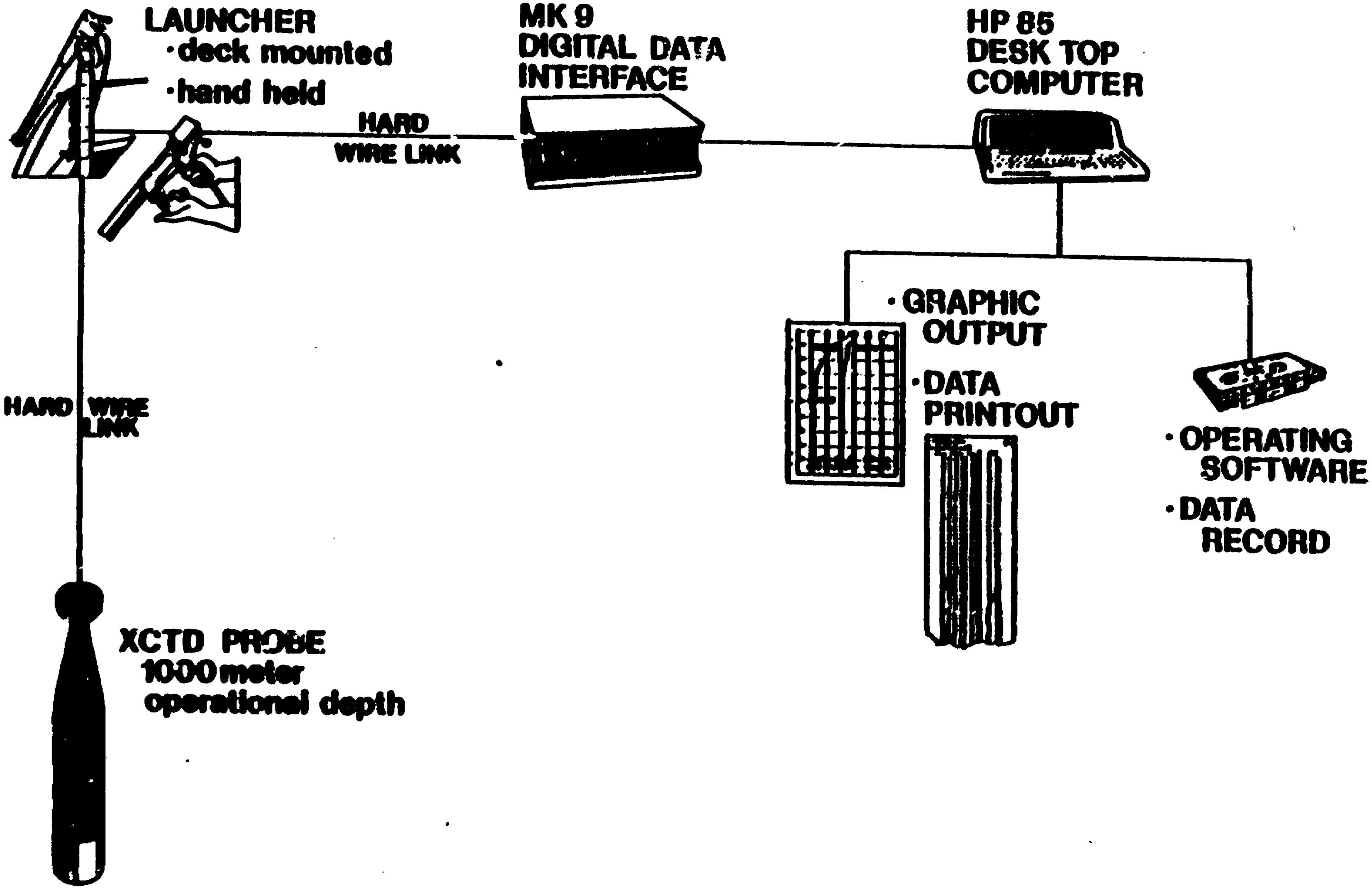


Figure 2.0 XCTD Profiling System

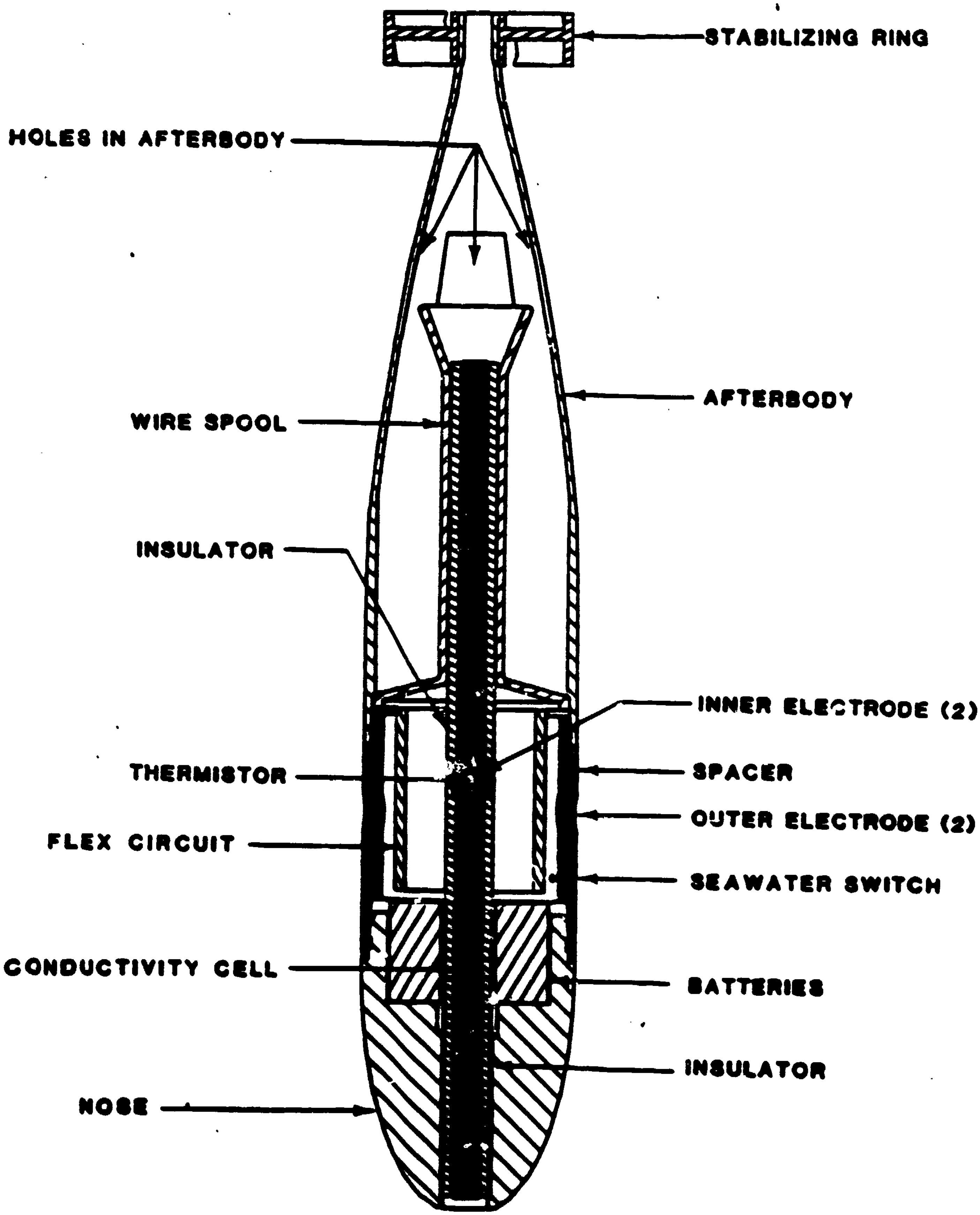


FIGURE 2-1: XCTD PROBE

2.1.2 Deck Gear Subsystem

The deck gear subsystem consists of a modified Sippican MK9 Digital Interface unit and the Hewlett-Packard HP 85 computer. Modifications to the MK9 include the addition of an XCTD personality card to receive and process XCTD unique signals. In addition, changes to the controller board PROM have been made to add XCTD to the list of Sippican probes that the unit will process.

Software for the HP 85 computer has been updated to include XCTD processing. The modified software receives, stores, and processes raw data from the probe, calculates temperature, conductivity, salinity, and depth from the probe in nearly real time. Neither of the deck gear modifications prohibit the use of other Sippican probes with the updated deck gear.

2.2 System Trades Summary

At the time that XCTD was first proposed, it was decided that cost goals consistent with expendable instruments could be met only if the material costs associated with the probes was kept low. The costs associated with temperature and conductivity sensors interchangeable to the accuracy required for the instrument were found too high for the expendable probe.

An alternate approach that transferred the costs from the probe to capital expenditures at the factory was found: to accurately calibrate each and every XCTD probe at the factory prior to probe packaging for shipment. This approach required the following developments.

2.2.1 Expendable Sensors Stability Approach

The expendable conductivity cell is to be fabricated from Pyrex glass. The material is chosen because of its long term dimensional stability and its small thermal coefficient of expansion.

The temperature sensor was chosen to be a glass encapsulated thermistor. Encapsulating thermistors in glass retards the rate of change of resistance (at a given temperature) with time to preserve the resistance vs. temperature relationship. Details about the stability are described in section 7.0 of appendix A to this report.

2.2.2 Expendable Electronics Stability Approach

The long term stability in gain and offset associated with probe electronics can not be guaranteed with the same level of confidence as the sensors exhibit. It is possible for the electronics to drift by an amount that could contaminate the accuracy of the factory calibration unless steps are taken to account for the drift. Sippican has chosen to add two "calibration" resistors to the probe electronics whose resistance and stability characteristics are precisely known. Further, the resistors are placed in series with the temperature and conductivity sensors and each sampled sequentially during every data collection cycle. In this way, the transfer function of the electronics between the sensor chain and the output is calculated with every data transfer.

2.2.3 Expendable Instrument to Deck Gear Data Transmission

Transmission of data from the probe is via two conductor, 39 AWG wire, similar to that used with other Sippican products. Since the sensors and calibration resistors are sampled sequentially, a time multiplexed format for data transmission was chosen. Time multiplexing permits less electronics in the probe (lowering cost) at the expense of more complicated electronics at the deck gear. The resistances associated with the sensors and calibration resistors are converted to frequency and transmitter along the BT wire to the deck gear. It was discovered during the course of the program that it is necessary to provide a "quiet time" in the transmission of the data during the time that conductivity sensing was in progress. Accordingly, the data format was designed to accommodate this requirement. Figure 4.2 is a diagram showing data frames from the old and new signal transmission formats.

3.0 EXPENDABLE PROBE SUBSYSTEM DESCRIPTION

3.1 Sensors Description

3.1.1 Conductivity Sensor

The sensor to measure the electrical conductivity is a four electrode cell developed at Sippican with the consultation of Mr. Neil Brown. The cell itself is fabricated from standard wall Pyrex glass tubing whose length is 221 mm and internal diameter 4.0 mm. Two electrodes, made from gold flashed coper-bronze eyelets, reside at the center of the cell's length. Two additional electrodes reside on the outer surface of the probe, fabricated from the same material as the internal electrodes. The cell constant, that quantity that relates measured cell resistance to electrical conductivity of the contents of the cell is given by

$$R = (1/C)(L/4A)$$

where R: The measured resistace
C: The conductivity of the cell's contents
L: The length of the cell
A: The cross-sectional area of the cell.

Then,

$$C = (1/R)(L/4A) = (1/R)Kc$$

So, the cell constant Kc is given by

$$Kc = L/4A$$

for the electrode configuration we have chosen. Using the cell dimensions mentioned above,

$$Kc = 44.0/cm, \text{ nominal}$$

for XCTD.

3.1.2 Temperature Sensor

The temperature sensor selected is the Thermometrics model P20BA102M glass encapsulated thermistor. This particular device was selected because of its known stability characteristics, measured by the National Bureau of Standards (Refer to Appendix A), its fast time constant, and the small cross-sectional area (to minimize cell flow restrictions). The thermistor is located at the center of the conductivity cell, mounted through a hole in one of the conductivity electrodes, and exposed to the flow of water through the cell. Figure 1.2 shows the conductivity cell and thermistor arrangement.

3.2 Probe Subsystem Mechanical Description

3.2.1 Canister Assembly

The canister assembly consists of a spool of 2000 meters of wire, for payout as the launching vessel proceeds underway, and an ABS plastic protective sleeve. A metallic launch pin connects the canister and XCTD probe until the time of launch. The canister spool interfaces electrically with the various probe launchers to send XCTD signals to the deck gear.

3.2.2 Probe Assembly

The XCTD probe provides a leak-proof pressure housing for the sensors and electronics, the probe wire spool, and a hydrodynamic shape for a consistent probe fall rate. Electrical exposure of the four conductivity electrodes and two probe power-on electrodes is provided. The probe is 29.5 cm in length, 5.0 cm in diameter, and has a mass of 280 grams.

3.2.3 XCTD Sensors Response Characterization

Tests of the XCTD sensors were carried out at the facilities of NAVOCEANO in Bay St. Louis, MS. Appendix C to this report is a paper presented to the Marine Technology Society Oceans '87 conference. The results of the test indicate that the temperature response time of 90 milliseconds for full response and the conductivity sensor response time of 100 milliseconds are well matched. These times, coupled with the probe fall rate indicate a cell flushing length on the order of 80 to 160 cm.

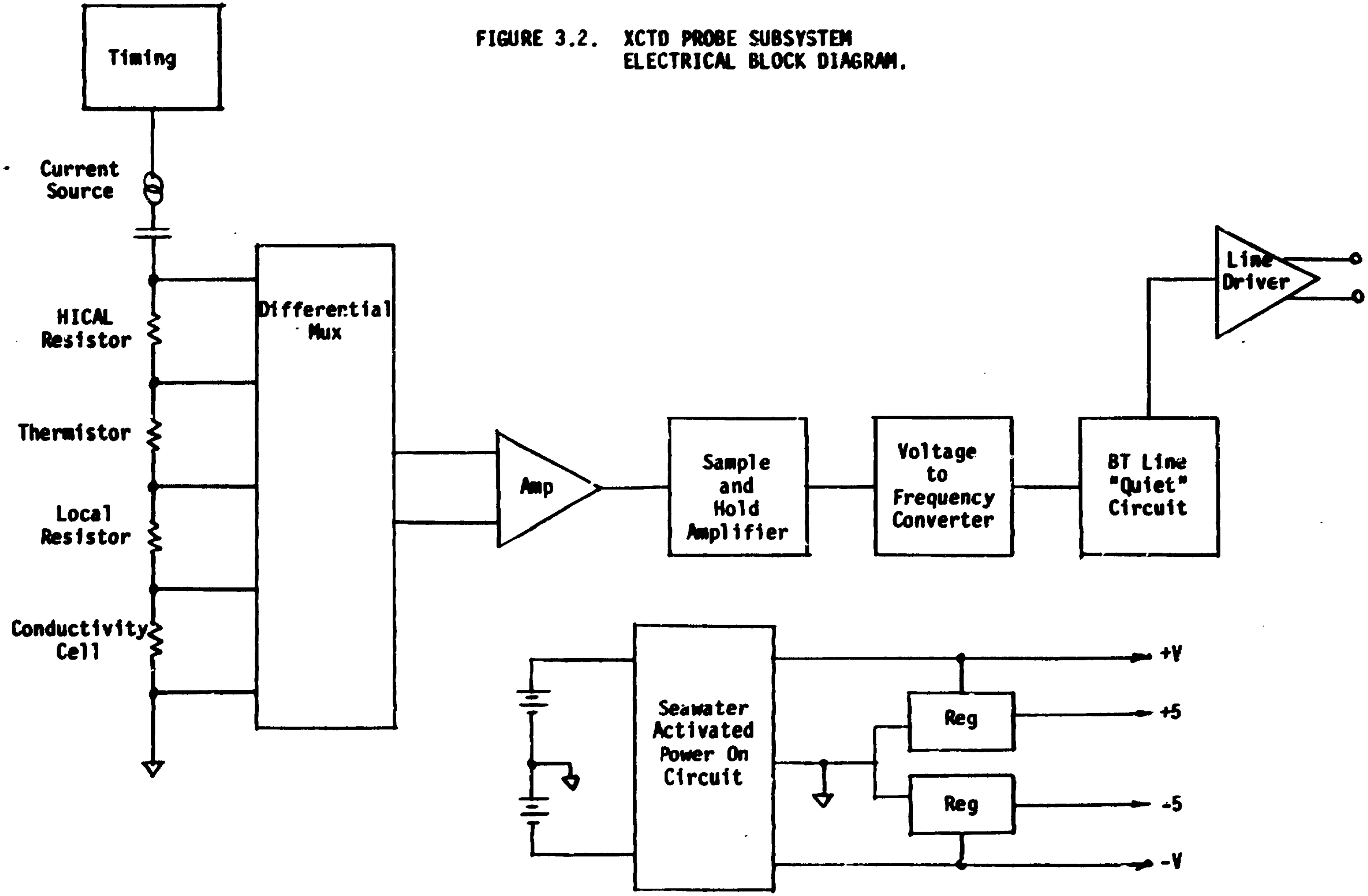
3.3 Probe Subsystem Electrical Description

The probe electronics are described in block diagram form in figure 3.2. An alternating current source supplies current to a series-connected chain of calibration resistors and the two sensors. This "sensor chain" is so connected to assure that equal currents flow through the sensors and calibration components. Since the calibration resistors are very well known, the voltage developed across the sensors can be accurately known.

Each of the sensor chain elements, the high calibration resistor (HICAL), the thermistor, the low calibration resistor (LOCAL), and the conductivity cell are sampled sequentially. The current flowing through each of the resistance elements causes a voltage to be developed across the element. This AC voltage is sampled, amplified, and input to a sample and hold amplifier. The sample and hold device effectively converts the sensor AC signal to a DC voltage suitable for input to a voltage-to-frequency convertor. The V-to-F generates a frequency proportional to the resistance of the sensor or calibration element currently being sampled. The BT line drivers supply the current necessary to impress the frequency onto the probe end of the wire link.

Power for the probe is furnished by chemical batteries within the probe. Four alkaline manganese dioxide batteries with 120 mA-hr capacity supply +/- 12 vdc to power the probe during the at-factory calibration and during actual probe deployment. The battery voltage is regulated to +/- 5.0 vdc to operate most of the probe electronics. The full battery voltage is used to power the BT line drivers to impress the maximum voltage possible across the BT wire. The regulators used permit the probe voltage to drop to +/- 7 vdc before the operation of the electronics is affected. Laboratory tests at -3 C show that the batteries may be operated continuously for 25 minutes before the 7 vdc threshold is reached. At room temperature (23 C), battery voltage dropped only to 8.80 vdc after 30 minutes of continuous operation. The total anticipated calibration time and probe deployment operation time is expected to be about 8 minutes.

FIGURE 3.2. XCTD PROBE SUBSYSTEM ELECTRICAL BLOCK DIAGRAM.



4.0 DECK GEAR SUBSYSTEM DESCRIPTION

4.1 Sippican MK9

The deck gear used in all laboratory development tests and at sea for testing has been a modified Sippican MK9 data acquisition unit. XCTD unique software has been added to the other probe software and has been used for all development and at-sea tests. Figure 4.1 shows the MK9 operation in block diagram form.

Consistent with Sippican's approach with other probes, an XCTD unique personality card has been developed to fit within the MK9, in an existing card slot. The personality card is designed to acquire XCTD signals, perform analog signal processing, and convert analog data into a digital format. Digital words, corresponding to the frequencies from the probe are transmitted to the MK9 controller card. The deck gear accomplishes the analog to digital conversion as follows: Four zero crossings of the probe frequency corresponding to a sensor output define a window. The beginning of a data packet is detected and a 10 msec time delay is inserted to allow transient effects of the BT transmission line to damp out. At that time, a window is opened for a precise number of probe frequency zero crossings. The deck gear master clock (6.0 MHz) frequency is counted during the time that the window is open. The digital count that results is converted to a digital word and is transferred to the host computer via the IEEE-488 bus. A timing diagram that shows the above described process is included as Figure 4.2.

The data frame, 250 msec in length, consists of frequencies corresponding to LOCAL, conductivity, HICAL, and temperature, in that order. Since the frequency range associated with the two calibration components is known, the position of LOCAL and HICAL are known within the data frame. Then, temperature data are uniquely located between LOCAL and HICAL and conductivity data are uniquely located between HICAL and LOCAL.

The MK9 controller card used is identical with previous cards with the exception that the ROM on board has been modified to include XCTD signal capability. As such, MK9's with XCTD capability will support Sippican's XBT, AXBT, XSV, and AXSV probes.

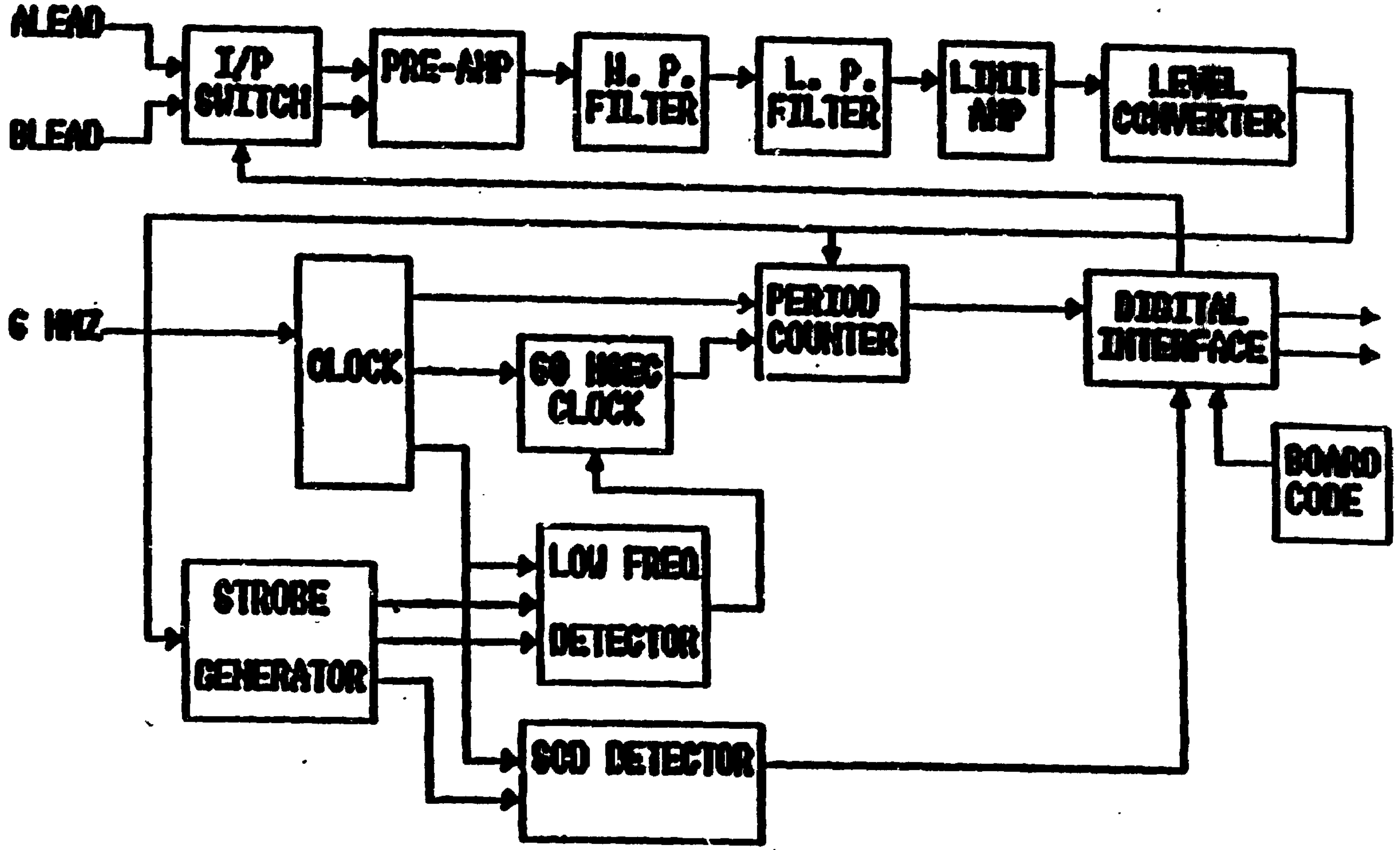


FIGURE 4.1 SIPPICAN MK 9

XCTD SIGNAL CONVERSION CARD

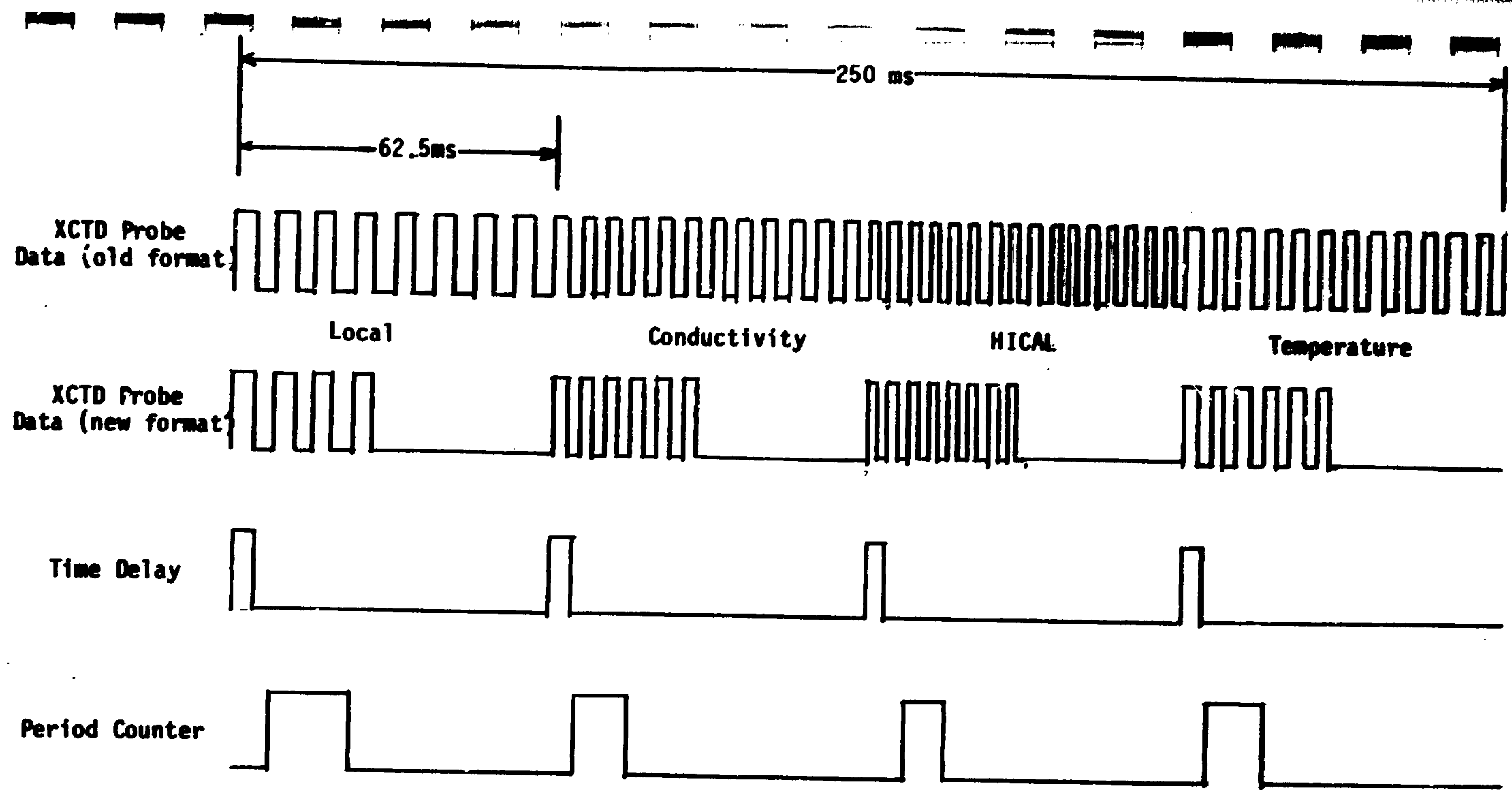


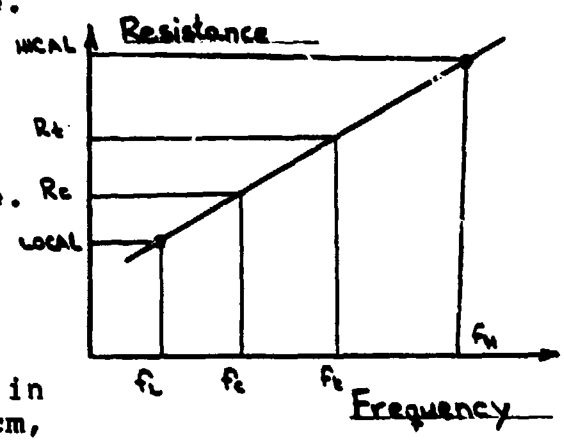
FIGURE 4.2. MK 9 XCTD WAVEFORMS.

4.2 HP 85 Software Description

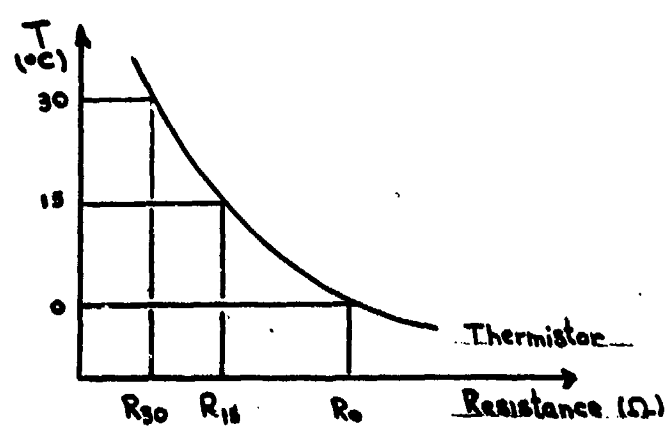
Software for the HP 85 has been updated to incorporate XCTD into the family of Sippican's environmental probes. Software that supports XCTD will continue to support the previously available family of ocean products.

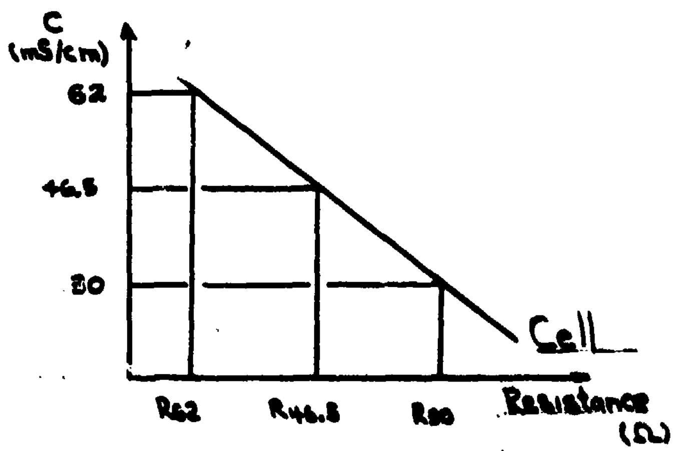
During probe drop, the HP 85 collects data via the IEEE-488 bus from the MK9. The data consists of a digital signal indicating start of descent and digital words indicating the HICAL frequency, temperature frequency, LOCAL frequency, and conductivity frequency. These data are stored in internal memory and later transferred to magnetic media for archival purposes. Time since probe start of descent is incremented in 62.5 msec blocks for each iteration of the temperature or conductivity segment received.

During probe drop, the following processing occurs: The frequency to resistance transfer function of the probe is ascertained by means of the frequencies associated with the HICAL and LOCAL resistors for each data frame. That is to say, since HICAL (3000 ohms) and LOCAL (300 ohms) are precisely known, the resistance to frequency transfer function for that data frame is known. The transfer function is shown in the figure. The frequency that corresponds to temperature and that corresponds to conductivity in a particular data frame may then be converted to the sensor resistance using the transfer function established for that data frame. At this point in the processing, then, the resistance of the thermistor and of the conductivity cell for a particular data frame are known.



In order to establish temperature in degrees Celcius and conductivity in mS/cm, the calibration factors established at the factory must be employed. Calibration data taken at the time of probe manufacture (and represented by the accompanying figures) are used to generate temperature vs. thermistor resistance and conductivity vs. cell resistance as shown.





Each of the sensor's resistance is converted to the appropriate primary unit by application of the curve generated at calibration time at the factory. Since the calibration data are probe-unique, it is imperative that data from a particular serial number probe is applied to data from that particular probe.

Probe depth is calculated from measured time and an empirically derived and verified drop rate. From the drop rate data, the following equation has been found:

d = 3.248 t - 0.000495 t^2

where

d: Depth in meters

t: Time in seconds since the start of descent

The quadratic term accounts for the change in mass of the probe as wire pays off and for the increase in viscosity of the colder water at depth.

The temperature and conductivity calculated from the primary measurements are plotted on the HP 85 screen as a function of depth. In addition, salinity may be calculated from temperature, conductivity, and depth, using PSS-78, if desired.

5.0 CALIBRATION SUBSYSTEM DESCRIPTION

This section of the report describes the calibration approach and procedures employed to date. The procedures include many "tricks of the trade" learned by experience and by participation in the learning process by representatives of the Woods Hole Oceanographic Instituition and from Neil Brown Instrument Systems, Inc.

5.1 Calibration Approach

As was described elsewhere in this report, the approach to the low cost XCTD was to calibrate each probe at the time of manufacture and to load the calibration data into the processing chain for each probe at the time of probe launch.

It was determined that three calibration points for temperature and three points for conductivity are needed to adequately fit a curve of measured parameter vs. resistance to meet our accuracy goal. Details are included in appendix A to this report.

The following table shows the conductivity expected from baths whose salinity was prepared at 38 parts per thousand and whose temperature is as indicated.

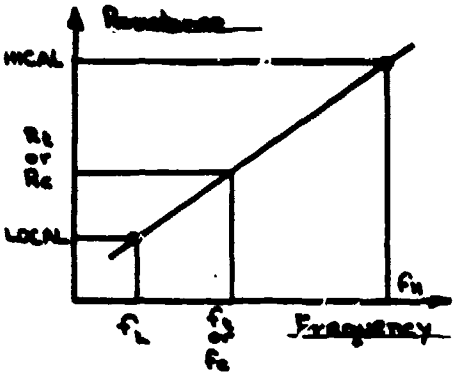
Conductivity of 38 ppt Water at the Indicated Temperature

Calibration Point	Temperature (C)	Conductivity (mS/cm)
High	29.5 to 30.5	60.7 to 64.8
Mid	14.5 to 15.5	44.6 to 47.0
Low	-1.5 to -0.5	29.2 to 31.5

The data indicates that maintaining the bath at 38 ppt and varying only the temperature yields calibration bath conductivities that span the range of oceanographic interest. The advantage of the constant salinity is twofold: First, calibration time is decreased since salt needn't be added to increase the conductivity at the beginning of a new calibration process. Secondly, the probes may be moved from one bath to another without changing the salinity of the baths.

At each of the three calibration points, the probe output is sampled simultaneously with the output of a calibration reference instrument. The frequencies associated with the thermistor, LOCAL, conductivity cell, and HICAL are sampled and stored along with the bath temperature and conductivity as indicated by the calibration reference.

The frequencies associated with the HICAL and LOCAL resistors are used to calculate the probe electronics transfer function as shown in the figure. The frequency associated with the thermistor and conductivity cell are converted to their resistance using the transfer function curve. Stored in memory and on magnetic media, then, are sensor resistance (Rt or Rc) vs. the reference instrument measured bath temperature and conductivity.



The probe is immersed in a second and a third set of temperature and conductivity conditions and the procedure repeated. Raw data from the calibration baths correspond to data shown as stored in the following table:

CALIBRATION CONSTANTS CALCULATION DATA

Calibration Point	Calibration Resistor Frequency LO	HI	Thermistor Resistance	Bath Temp.	Cell Resistance	Bath Conductivity
HI	Flh	Fhh	Rth	Th	Rch	Ch
MID	Flm	Fhm	Rtm	Tm	Rcm	Cm
LO	Fll	Fhl	Ttl	Tl	Rcl	Cl

Curves are fit through the data so collected as follows: For temperature, the Steinhart-Hart equation is used.

$$1/Th = Ka + Kb(\ln Rth) + Kc(\ln Rth)^3$$

$$1/Tm = Ka + Kb(\ln Rtm) + Kc(\ln Rtm)^3$$

$$1/Tl = Ka + Kb(\ln Rtl) + Kc(\ln Rtl)^3$$

These equations are inverted to solve for Ka, Kb, and Kc, which become the temperature calibration constants for a particular probe.

In similar fashion, conductivity constants are found:

$$Ch = Kd + Ke(1/Rch) + Kf(1/Rch)^2$$

$$Cm = Kd + Ke(1/Rcm) + Kf(1/Rcm)^2$$

$$Cl = Kd + Ke(1/Rcl) + Kf(1/Rcl)^2$$

These equations are inverted to solve for Kd, Ke, and Kf, which become the conductivity calibration constants for a particular probe.

The above procedure makes the following assumptions:

1. The reference instrument indicates the bath temperature and conductivity accurately.

2. The bath is uniform in temperature and conductivity to the required accuracy, both spatially over distance between XCTD and the reference sensor, and temporally over the time required for calibration.

3. XCTD thermistor self heating effects are small.

The reference instrument referred to in the above list is the Neil Brown Instrument Systems Model CT-III Calibration Instrument. In essence, the instrument sensors and electronics are identical to the popular Neil Brown CTD, but without the pressure housing required for the at-sea unit. Published specifications are as follow:

Variable	Accuracy	Resolution	Stability	Range
Temperature (C)	+/- 0.005	0.0005	0.001/mo	-3 to 32
Conductivity (mS/cm)	+/- 0.005	0.001	0.003/mo	1 to 65

The accuracy of the reference is a factor of six times better than the XCTD accuracy goals, which is adequate for a calibration reference instrument.

The calibration bath used to date has been a Guildline Model 9734. Specifications for the unit are listed:

Temperature Range	-9.9 to 65 C
Regulation	+/- 0.002 C over 24 hr
Gradients	< +/- 0.002 C

Since we are measuring the temperature and conductivity independently, the important considerations for the bath are its stability and the absence of gradients within the bath water. We have measured our bath to be uniform in temperature to +/- 0.001 C over the entire bath volume. Typical calibrations take about one minute per calibration point--a time over which the bath proved to be stable.

Measurements of the thermistor self heating have been conducted at Sippican. Self heating in still water was found to be 0.005 C. A flow past the thermistor as low as 2 ml/sec was enough to make the self heating effect imperceptible.

5.2 Calibration Procedure

The procedure that has evolved for calibration of XCTD's for use at sea is discussed in this section.

The process begins by having our reference instrument checked by Neil Brown Instrument Systems to measure the drift in temperature and conductivity. The drift data are entered into the software used for acquisition and processing of calibration data.

The Guildline bath is thoroughly cleaned and filled with fresh water. Aquarium filters and pumps are set up to circulate water through the filtering medium. After the water has circulated for about 24 hours, the filter medium is changed and salt (a commercial marine mix) is added to bring salinity to about 38 parts per thousand. Salt is permitted to dissolve into solution overnight.

The reference instrument, XCTD holding fixture, and a heat exchanger that directs flow through the conductivity cell are fitted into the bath. The bath temperature is set to 35 C and kept there for 24 hours to degas the bath water. After the degassing procedure, the bath is set to 30 C, the first calibration point, and allowed to stabilize there.

Probes to be calibrated are placed in a temperature chamber set at the bath temperature. The purpose of this step is to pre-condition the probes to the bath temperature to minimize the temperature change to the bath upon probe immersion. The probe turn-on circuit electrodes have been covered with a non-conductive tape to keep the probe power turned off until data collection is ready to begin. When all is ready, the electrodes are uncovered and the probe data and the reference sensors data are collected via the HP 85 computer. Fifty data points are sampled. The mean thermistor resistance, cell resistance, temperature, and conductivity of the bath are determined. The standard deviation of the data is calculated. Data points outside of one standard deviation are removed from the data and a new mean for each variable is computed. It is these averaged data that are stored as calibration data for the high calibration bath. All probes that are ready for calibration are calibrated at this single temperature and conductivity point before altering the bath for the next calibration temperature and conductivity.

The bath temperature is lowered to 15 C and the above procedure is repeated.

The bath temperature is lowered to -1 C and the above procedure is repeated.

The calibration constants are calculated as previously described and are stored on magnetic media for use at sea.

6.0 SEA TESTS SUMMARY

Many tests at sea have been carried out over the course of the development program. Some of the tests had been arranged with cable lowered CTD's so that temperature and conductivity data could be compared. Described below are tests that were important in the development of the XCTD system in that they exposed significant problems in the design or that they verified that the design problems were resolved. Singled out are the last two sea tests, held in September and November of 1987 for more detailed discussion. In addition, the sea test report for these two tests is included with this report as appendix B.

6.1 October 1984 Sea Test (R/V Weatherbird, Bermuda)

The objective of the test was to compare the XCTD's with one another to seek probe-to-probe repeatability. The test results, however, showed water leaks into the electronics cavity when the probes reached significant depths. In addition, the HICAL frequency was so severely attenuated over the BT transmission line that data from the greater depths was unusable.

6.2 April 1985 Sea Test (Polaris, St. Thomas)

The objective of the test was to demonstrate that a three piece conductivity cell with O-ring seals was immune to sea water leaks. Although the leak problem was solved, a new grounding configuration gave rise to a periodic "jitter" on the data that seemed to get worse with depth. If the jitter was ignored, probes intercompared with each other and with the Sippican Expendable Current Profiler (XCP) to within 0.11 C.

6.3 November 1985 Sea Test (R/V Knorr, C-SALT)

The objective of the test was to compare XCTD with a cable lowered CTD in the Caribbean where distinct salinity and temperature steps occur naturally. Temperatures compared to within 0.1 C and conductivities to within 0.21 mS/cm. The discrepencies were traced to a faulty mid-temperature and mid-conductivity calibration at the factory. Recalibration using the CTD at sea values showed much better agreement between CTD and XCTD. The "jitter" referred to above, however, was still present on the data, precluding a more careful comparison of data. Safeguards to the calibration process were instituted because of the problems encountered on this sea test.

6.4 May 1986 Sea Test (R/V Knorr, Gulf Stream)

The objective of the sea test was to compare XCTD performance with a CTD. Four of the seven traces were useable (three probes suffering data loss due to deck gear problems). The CTD data were never made available, due to funding constraints at Woods Hole, the operators of the CTD.

6.5 September 1987 Sea Test (R/V Weatherbird, Bermuda)

The objective of the test was to determine if electronics fixes to remove the "jitter" described above had worked. Deck gear problems caused no data to be collected real time. However, for the first time a workable analog tape backup of the data was available. Analysis of the data indicates that the "jitter" is gone. Analysis had indicated that the "jitter" was due to feedback of the BT wire frequency into the electrodes of the conductivity cell. The problem was removed by removing the signal from the BT wire at the time that sampling of the ocean was taking place. Figure 4.2 shows the old data format and the new one where the BT wire quiet time has been added.

To the accuracy possible with the analog tape data, seven of seven temperature traces were virtual overlays. Five of the seven conductivity traces were overlays.

A data drop-out problem between 25 and 50 meters was detected on several of the probes for the first time. The problem has been traced to a new BT wire line driver that was used for the probes for this test. The device has been replaced with one that can deal with the rate of change of capacitance that the BT wire experiences as sea water is forced into the spool of wire as pressure increases due to increasing depth.

6.6 November 1987 Sea Test (R/V Weatherbird, Bermuda)

The objective of the sea test was to compare the XCTD with a cable lowered CTD. Probes were of the same configuration as tested during the September 1987 sea test. Deck gear problems and the failure of the analog tape backup system caused a disappointing yield of data. Howver, the "jitter" was confirmed to be gone and temperature and conductivity, and calculated salinity accuracy goals, as compared with the CTD, seem to have been met.

7.0 FUTURE PLANS

Several items were learned during the course of the development program that will be applied to XCTD, now in pilot production at Sippican under joint NORDA/Sippican funding.

7.1 Expendable Probe Subsystem

The probe mechanical parts are in process of being tooled to bring manufacturing costs down. Tooled parts will also cause probes to be more nearly identical in their hydrodynamic characteristics, thereby contributing to stable probe fall and cell flushing rates.

Probe electronics built to date have been fabricated on flexible printed wiring boards. Our experience has shown that yields from the boards is to low for successful production of the boards. As such, electronics for future units will be fabricated on rigid printed wiring boards using surface mounted components.

Calibration data unique to a particular probe will reside with the probe for the production XCTD. The calibration constants calculated at the factory will be stored in a PROM within the canister assembly. At the time that the probe is placed in the launcher and prior to actual launch, calibration data will be read via the MK9 into the host computer. During probe drop, these calibration constants will convert raw data into temperature and conductivity for display. The raw data, however, will continue to be the data stored on magnetic media.

7.2 Deck Gear Subsystem

Two updates are planned for deck gear that supports the XCTD system. First, the capability to provide an independent back-up of the raw data will be provided. As a goal, we seek to make the data recorded to be indistinguishable in quality from data collected, recorded digitally, and processed in real time. The approach that we are currently exploring makes use of a pilot tone frequency added to the probe data for storage on analog tape. The pilot tone is detected on tape playback and causes the probe frequencies to be adjusted by the amount of tape speed error measured.

The second planned update is the replacement of the HP 85 computer with the family of IBM compatible computers. The newer, faster, and enhanced graphics capabilities of the IBM compatibles will enhance the user data return and permit second order corrections for the probe fall rate. Multiple MK9's may be controlled from the same host computer, allowing simultaneous drops of any of the family of Sippican expendable probes.

7.3 Calibration Subsystem

A calibration subsystem is under development at Sippican to enable calibration of probes in quantities of 4000 unit per year. Efforts are being concentrated in three areas.

The design of the calibration bath(s) is underway. Requirements for the baths and necessary support equipment have been specified.

A strategy for traceability of temperature and conductivity reference instruments to known standards is under development. We have elected to use conductivity instead of salinity as the standard because of the difficulty in obtaining and storing large quantities of sea water whose temperature, conductivity, and salinity relationship is known (such as Sargasso Sea water).

Finally, the Calibration Data Entry Subsystem described in section 7.1 is under development.

APPENDIX A

R-1259

XCTD PHASE I PROGRESS REPORT

(13 July 1983)

Sippican Ocean Systems, Inc.
Marion, Massachusetts

R-1259

XCTD PHASE I PROGRESS REPORT

(13 July 1983)

Sippican Ocean Systems, Inc.
Marion, Massachusetts

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1.0 INTRODUCTION

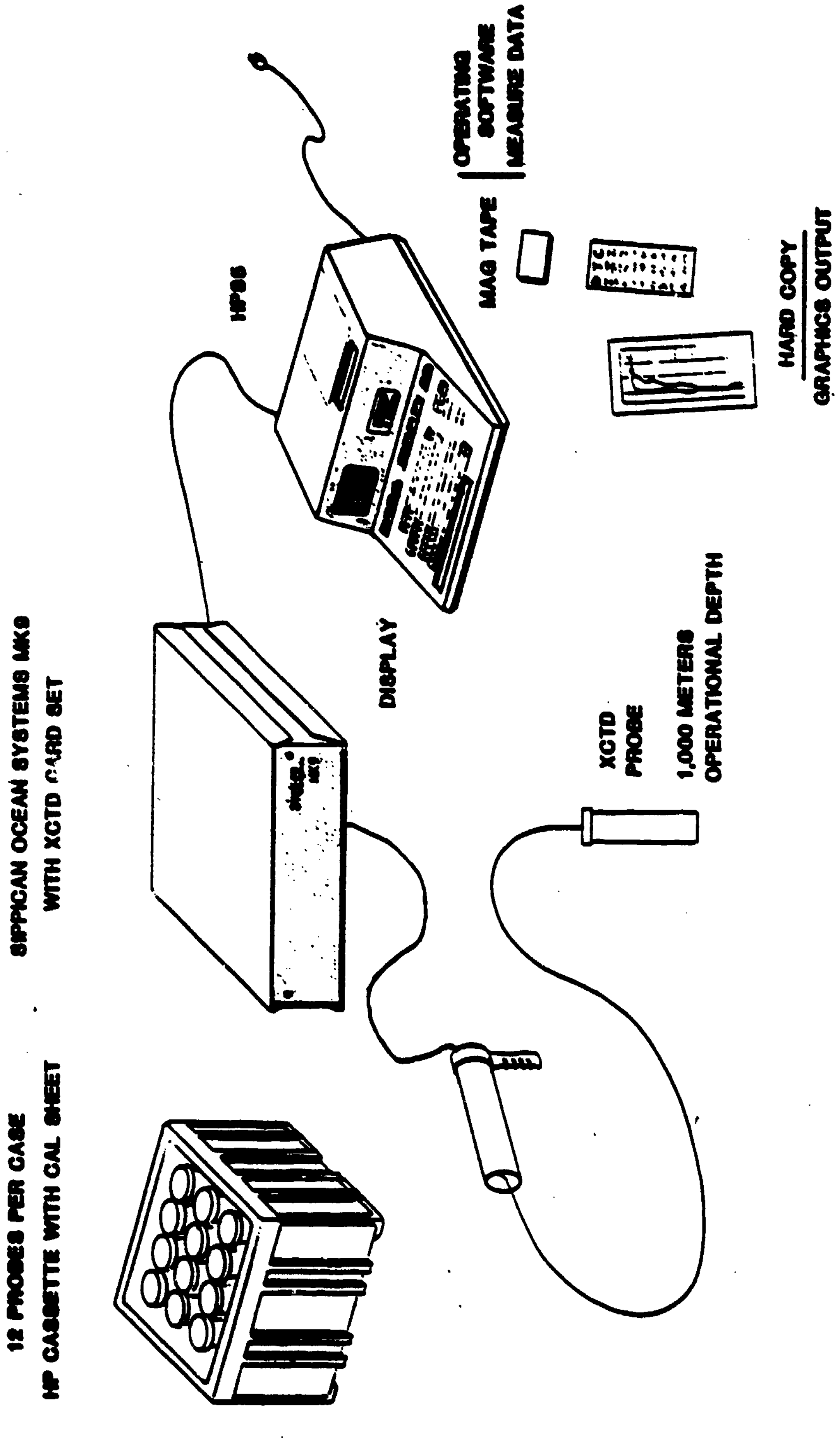
Sippican under Contract N00014-82-C-0579 is developing an Expendable Conductivity and Temperature probe (XCTD). Phase I of that contract, as defined in Report R-1087A, encompasses the conceptual design and laboratory testing of temperature and conductivity sensors and associated circuitry for the expendable probe. This report describes the activities and results of Phase I of this contract. The report is an overall description of the XCTD probe and its progress to date. A general description of the circuit operation, lab setup, calibration procedures, software and data formatting, transmission, detection and processing is presented. The attained system accuracies, the sources of inaccuracies and how they might be improved in the final configuration is also presented. Descriptions of the model conductivity cell, thermistor, and model probe are included along with their performance test results. Finally, in the last section the remaining major design areas are outlined.

2.0 EXPENDABLE, CONDUCTIVITY, TEMPERATURE, DEPTH (XCTD) SYSTEM

The XCTD System, as presently configured, is shown in Figure 2.0-1. The free falling XCTD probe transmits time multiplexed frequency modulated data up a standard 39 gauge BT wire pair. The time multiplexed data consists of sequential samples of conductivity, temperature and calibration data. The BT wire is terminated at the hand, deck, or thru-hull launcher and interfaced to the Sippican MK-9 Recorder with an XCTD card set via the launcher cable. The MK9 Recorder demultiplexes the data samples and measures the frequency of the appropriate data samples. These data samples are transferred to the Hewlett Packard 85 desk top computer where real time calibration data is compared to initial (time of manufacture) calibration data to determine any changes in gain and offset of the electronics. These changes in gain and offset are used to correct the real time conductivity and temperature data. The corrected data is displayed on the HP85 display, printed on the printer and stored on the cassette. The data reduction and display performed by the HP85 occurs almost simultaneously with the probes descent, so data is available very nearly real time.

The accuracy requirements for the XCTD system were defined in Sippican Report R-1087A as ± 0.03 mmho for conductivity and ± 0.03°C for temperature. An initial assessment of sensor, electronics and processing errors resulted in the following apportionment of allowable tolerances and errors.

	Sensor	Probe Electronics	Deck Gear Processing
Conductivity	0.01 mmho	0.01 mmho	0.01 mmho
Temperature	0.01°C	0.01°C	0.01°C



XCTD SYSTEM CONFIGURATION

FIGURE 2.0-1

2.0 EXPENDABLE, CONDUCTIVITY, TEMPERATURE, DEPTH (XCTD) SYSTEM

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	Sensor	Probe Electronics	Deck Gear Processing
Conductivity	0.01 mmho	0.01 mmho	0.01 mmho
Temperature	0.01°C	0.01°C	0.01°C

It is noted that the contributing errors are summed directly to provide the ± 0.03 mmho and ± 0.03°C total accuracy, rather than by the usual RMS method. This is to allow for worst case conditions with a preference to err on the safe side.

Preliminary analysis showed that for a suitable conductivity cell to be interchangeable, the dimensional accuracy required was not tolerable in an inexpensive expendable. For example, a tubular 3 or 4 electrode conductivity cell 8.0 " long by 0.157" I.D. requires a ± 0.000015 inch tolerance on its inside diameter in order to be accurate to ± 0.01 mmho. A similar case exists for the temperature sensor in that a device accurate to 0.01°C costs more than our total material budget for the XCTD probe.

The approach became to provide very stable resistor references in each probe and at the time of manufacture to calibrate the performance of an inexpensive but stable conductivity cell and an inexpensive but stable thermistor against the very stable resistors contained in each probe. At the time of probe deployment, the circuit performance with the reference resistors is compared to what it was when the probe was calibrated.

Any changes are calculated, and corrected for. This allows the accuracy of the conductivity cell and thermistor to be orders of magnitude less than before. The accuracy is obtained by factory calibration and stability.

The small drawback of this system is that the initial calibration data that is used to determine conductivity and temperature performance versus the reference resistors is unique to each probe and must be available at the time of probe deployment.

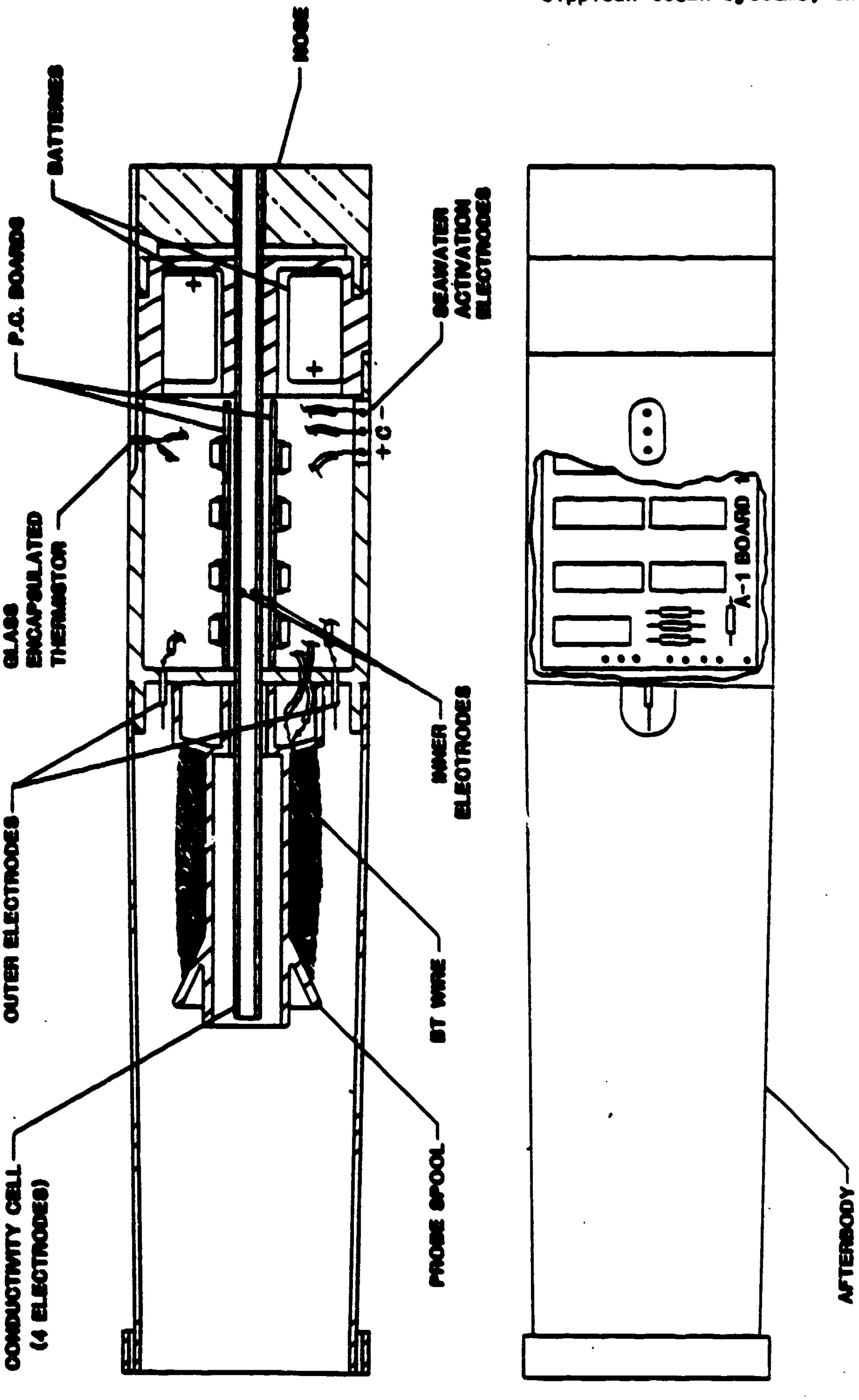
2.1 XCTD Probe

A prototype XCTD probe assembly, as shown in Figure 2.0-2, is comprised of a number of parts similar to other Sippican probe parts. The zinc nose provides a controlled rate of stable descent. The hole in the center provides water flow thru the glass tube of the conductivity cell. The electronics packages contain the batteries required for probe operation and the two printed circuit boards. Both the batteries and the P.C. boards are potted to ensure water integrity. The two outer electrodes of the four electrode conductivity cell protrude through the potting and are available to the outside water flow via holes in the probe afterbody. The afterbody houses the probe spool and attaches to the ABT canister spool. Both spools together contain approximately 2,560 meters of BT wire. This is sufficient for a 1,000 meter probe drop from a ship traveling at 12 knots. This is based on a probe sampling increment of 1 meter.

2.2 XCTD Probe Electronics

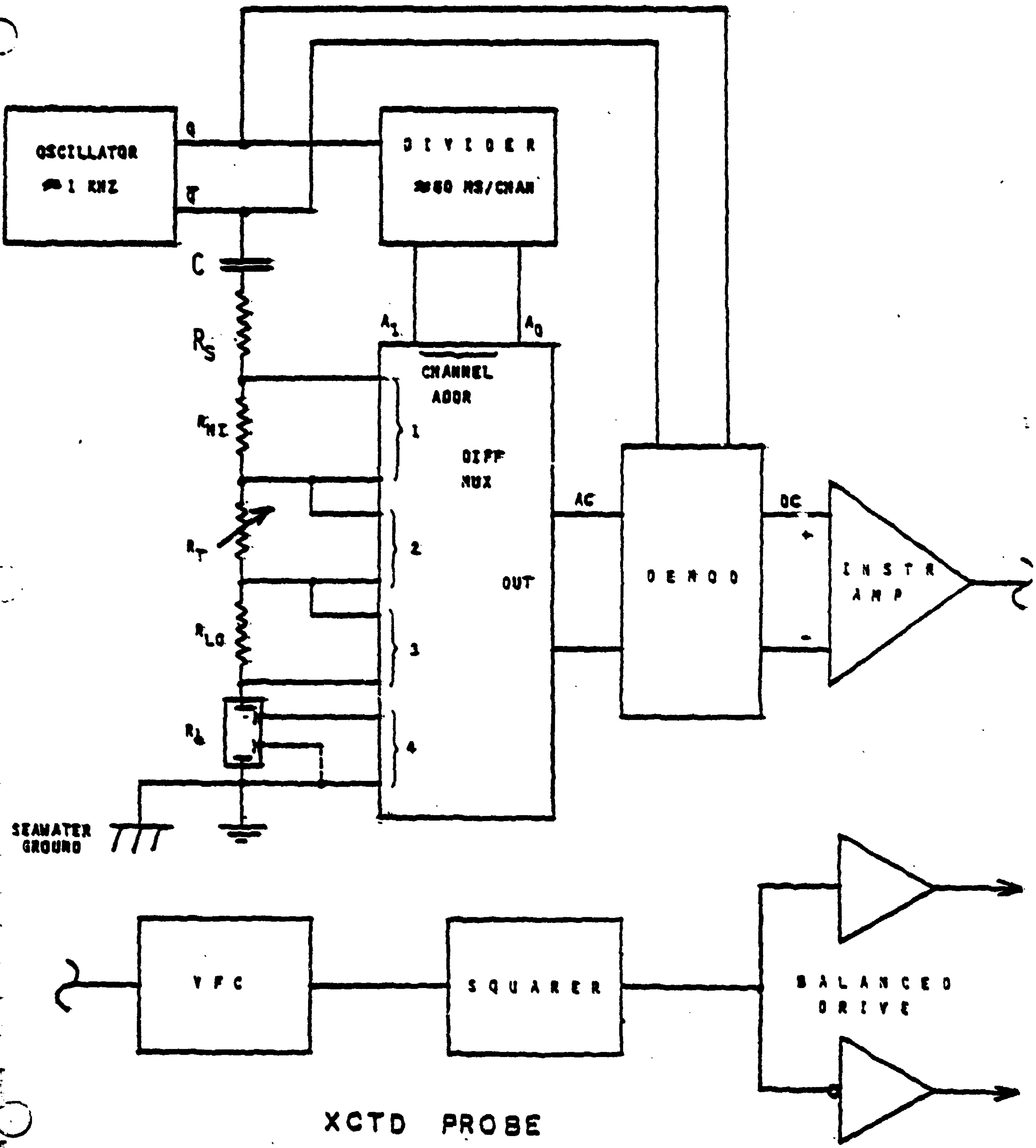
Functional

A block diagram of the XCTD circuit is presented in Figure 2.0-3. The basic function of the circuit is to sequentially measure the voltages across a high and low calibration resistors, a thermistor, and a conductivity cell, all connected in series, convert the four voltages to proportionate frequencies and transmit the frequencies as time multiplexed FM through a 2 conductor BT cable to a surface receiver. The thermistor resistance varies with temperature and the conductivity cell resistance varies with water conductivity. The key to an accurate measurement is knowing the exact resistance of R_{HI} and R_{LO} and knowing that they are stable with temperature and time. Vishay Type S102 resistors having a resistance tolerance of ± .005% and a temperature coefficient of 1 part per million per °C are used. The voltages across the thermistor R_T and the conductivity cell R_δ are therefore directly proportional to the voltages across



- PROTOTYPE -
XCTD PROBE LAYOUT

FIGURE 2.0-2



XCTD PROBE
FUNCTIONAL BLOCK DIAGRAM

FIGURE 2.0-3

R_{HI} and R_{LO} since at any one time the current through all the resistors is the same (assuming leakage and bias currents are zero). Using a balanced drive output all four frequencies are transmitted approximately four times a second through a 2 conductor BT cable to a surface receiver.

2.3 Operational

Referring again to the block diagram, the 1kHz oscillator is used to generate a square wave signal, which serves three functions as follows:

1. To drive the resistor chain consisting of R_S, R_{HI}, R_T, R_{LO}, and $R\delta$. The signal is AC coupled through the capacitor C thus providing a good symmetrical AC square wave.

2. To drive the divider which provides the channel address to the 4 channel differential multiplexer.

3. To drive the synchronous demodulator.

The AC voltages across R_{HI}, R_T, R_{LO}, and $R\delta$ are sequentially sampled by the differential multiplexer. The output of the multiplexer drives the synchronous demodulator, and the AC signal is converted to a DC signal of equal peak amplitude. This DC signal is amplified by the instrumentation amplifier, converted to a proportional frequency by the VFC (Voltage to Frequency Converter) and divided by two by the squarer for a 50% duty cycle square wave. Finally the signal is fed to a balanced driver, which drives the line with voltages of opposite polarity, reversing the polarities each ½ cycle. This provides a very large voltage swing which compensates for the heavy wire attenuation. Also, the induced currents in the wire cancel each other thus minimizing circuit interference since battery ground is also seawater ground via the conductivity cell electrodes.

2.4 Electrical

A detailed schematic is attached. The lkHz oscillator IC1 is a multivibrator. The frequency stability requirements will be dictated by the data receiving equipment and will be within the capabilities of IC1 - with the proper selection of external components. The $\bar{Q}$ output drives the resistor chain R_S, R_{HI}, R_T,R_{LO}, and $R\delta$. The Q output drives the divider chain IC2, IC3, and IC4. Both the Q and $\bar{Q}$ outputs are also the commutating signal for the quad bilateral switch IC6, which acts as the synchronous demodulator. A switch type demodulator, or commulator was used since it's response to changes in amplitude is fast compared to traditional type peak detectors. The output of the dividers provide the channel address to the differential multiplexor. Since the dividing chain divides the lkHz oscillator signal by 120, the output of IC4 addresses each of the four channels for 60 ms each, thus the voltages across R_{HI}, R_T, R_{LO}, and $R\delta$ are sampled for 60 ms each. The output of IC6 is fed to the differential input of the instrumentation amplifier IC7, whose high common mode rejection eliminates any common mode voltages and provides a ground referenced positive output.

The gain is 10 and is determined by external pin connections. The output of the amplifier is the input signal to the Voltage to Frequency Converter IC10 via the low pass R/C filter comprised of the 2K resistor and 1µf capacitor. This filter averages any ripple due to any imbalances (DC voltages) at the input to the differential multiplexer. The output of IC10 is a frequency proportional to the voltage input in the range of approximately 200 to 2200 hertz. The output frequency does not have the desired 50% duty cycle, and is thus squared by the divide by two circuit IC8. The resulting 100-1100 Hertz signal is AC coupled to a balanced driver output stage. When IC9, pin 12 is positive at about 6 volts, IC9 pin 10 is negative at about -6 volts. Therefore, IC9, pin 12, swings from 6 volts to -6 volts and IC9, pin 10, is simultaneously swinging from -6 volts to 6 volts thus the total voltage swing is 4 x 6 or 24 volts.

2.5 Power

The electronics is powered with four alkaline 9V batteries contained within the probe and provide a total of ±18V. The voltage is regulated down to ±12 volts. The alkaline batteries can be expected to retain 70% of their original capacity after two years if stored at temperatures less than 30°C, and at circuit current drains of approximately 30 ma are capable of powering the probe throughout its descent. The major advantage in using alkaline batteries is their low cost. Activation of the probe electronics will be via three electrodes on the outside of the probe body. These electrodes will be commoned to circuit ground, which is also seawater ground, upon contact with seawater. This will in effect pull the negative battery and the positive battery to circuit ground, thus completing the power/ground circuit.

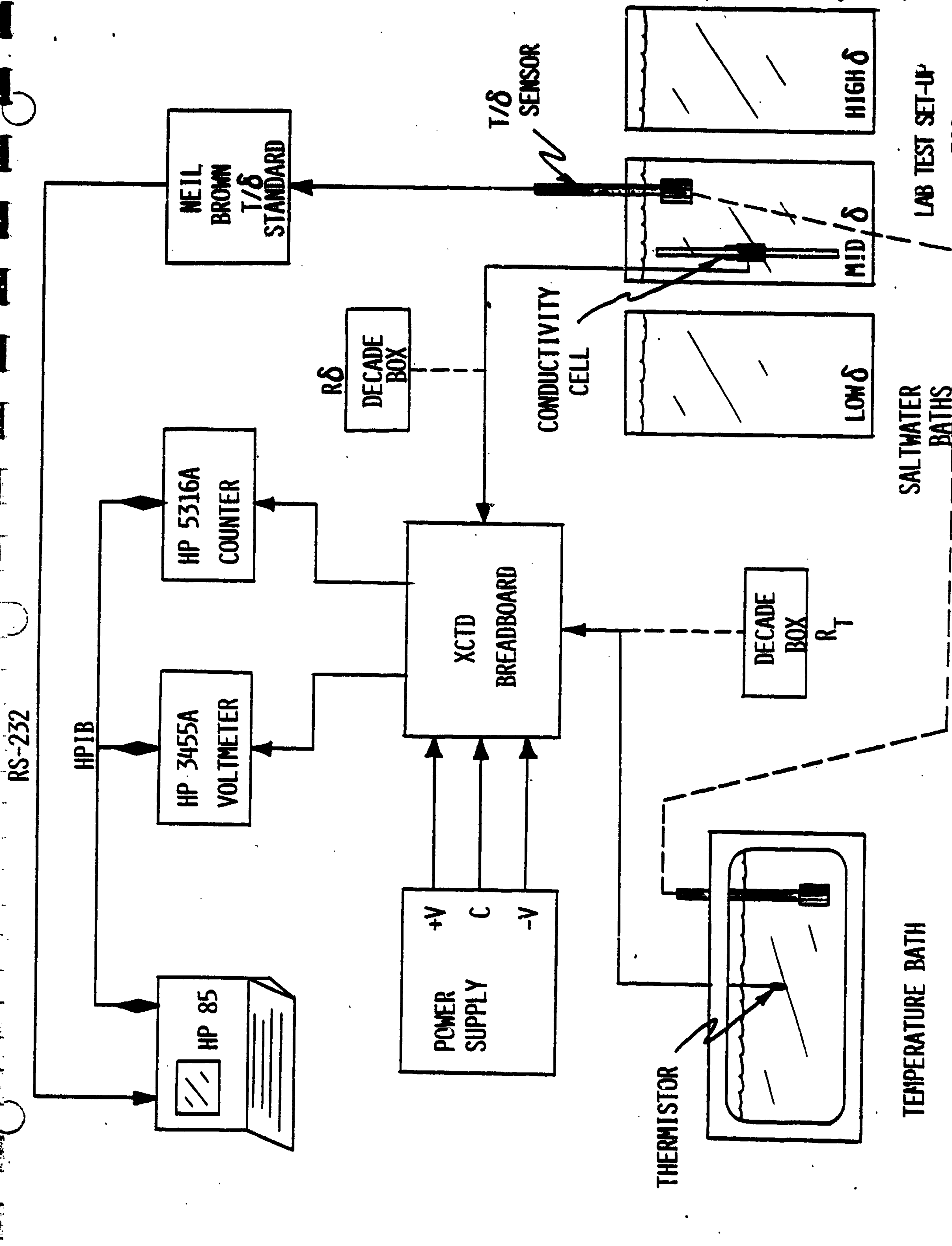
3.0 SYSTEM OPERATION

3.1 Laboratory Set-up

For the purposes of development testing of the electronics, conductivity cell, thermistor, and the accuracy demonstration of the final probe configuration, the lab set up shown in Figure 3.0-1, was assembled. The XCTD circuit as described in Section 2 is shown in the center. Its inputs are ±12VDC, R_T or a thermistor, and $R\delta$ or a conductivity cell. The outputs are the instrumentation amplifier output and the divide by two squarer and these are connected to the HP3455A voltmeter and the HP5316A counter, respectively. A special interface circuit to properly gate the counter-to-measure time intervals is included in the XCTD breadboard. This interface circuit is not part of the normal probe electronics and its function will be included in XCTD deck gear. An HP85 computer sequentially inputs data from the voltmeter and the counter via an HPIB interface bus and processes the data to determine temperature and conductivity. Subsequently, temperature and conductivity is also input as measured with the Neil Brown Model CT III Calibration Standard via the RS-232 link. The three seawater baths are mixed to provide three different levels of conductivity - low, middle, and high. These three conductivities are used to calibrate the conductivity cell. Similarly a microprocessor controlled temperature bath provides three levels of temperature to calibrate the thermistor. Both the temperatures and conductivities are known by measuring with the Neil Brown Standard. Also, temperature and conductivity can be independently profiled by varying the bath temperature and adding salt to the low conductivity bath, respectively.

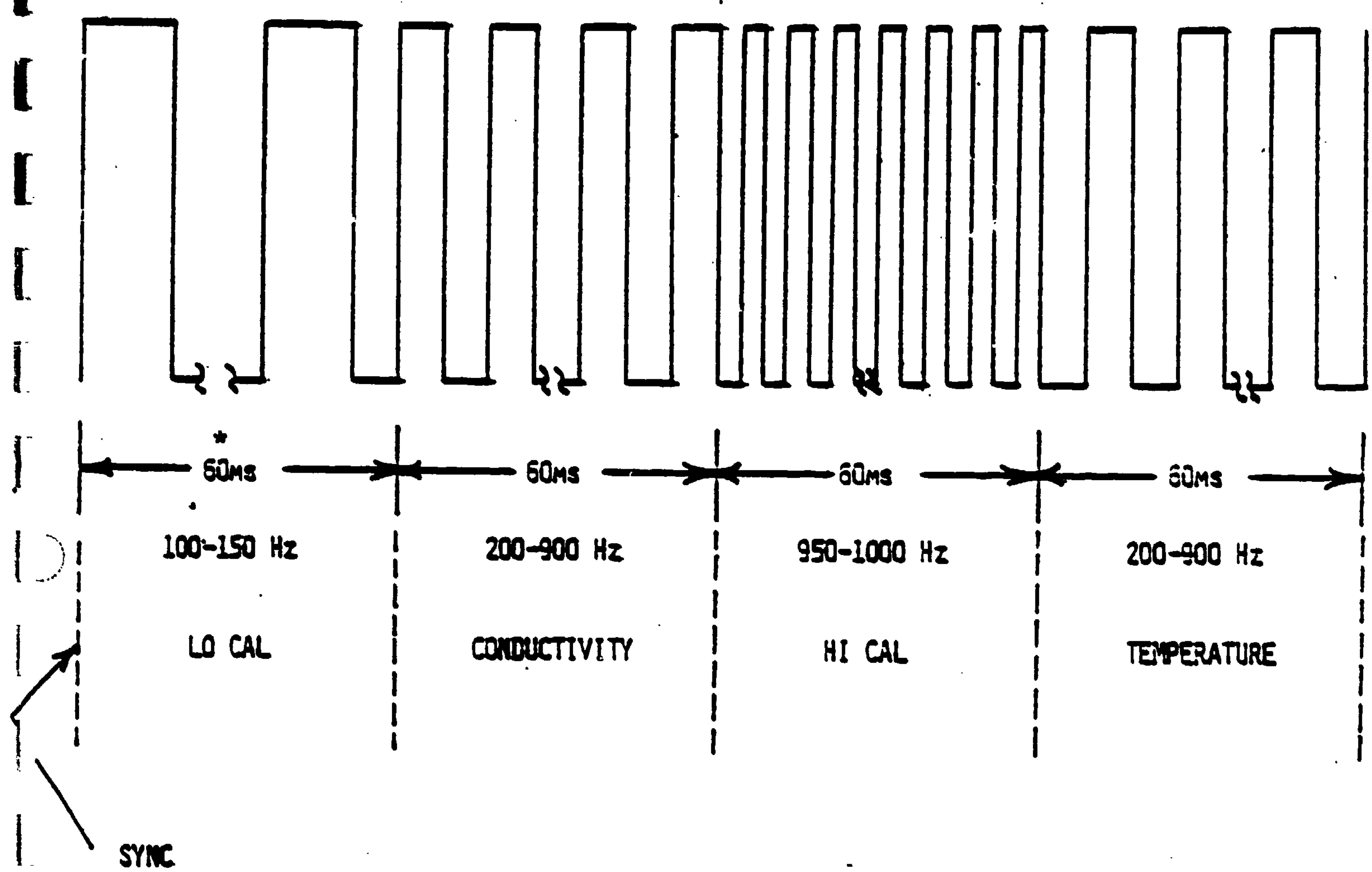
3.2 XCTD Communication and Timing

The calibration temperature and conductivity data is contained both in the voltage and frequency outputs of the XCTD circuit. The data output is formatted as shown in Figure 4. In order to properly gate the counter, an interface circuit was breadboarded to output a single pulse enveloping 2, 4, 6, 8, or 10 cycles (selectable) of each channel at a predetermined delay from the beginning of each channel.



LAB TEST SET-UP

FIG. 3.0-1



XCTD DATA XMISSION FORMAT

* For lab testing this time, has been slowed down to approximately 1 sec. to allow time for measurement. Applicable only to simulated XCTD processor.

FIGURE 3.0-2

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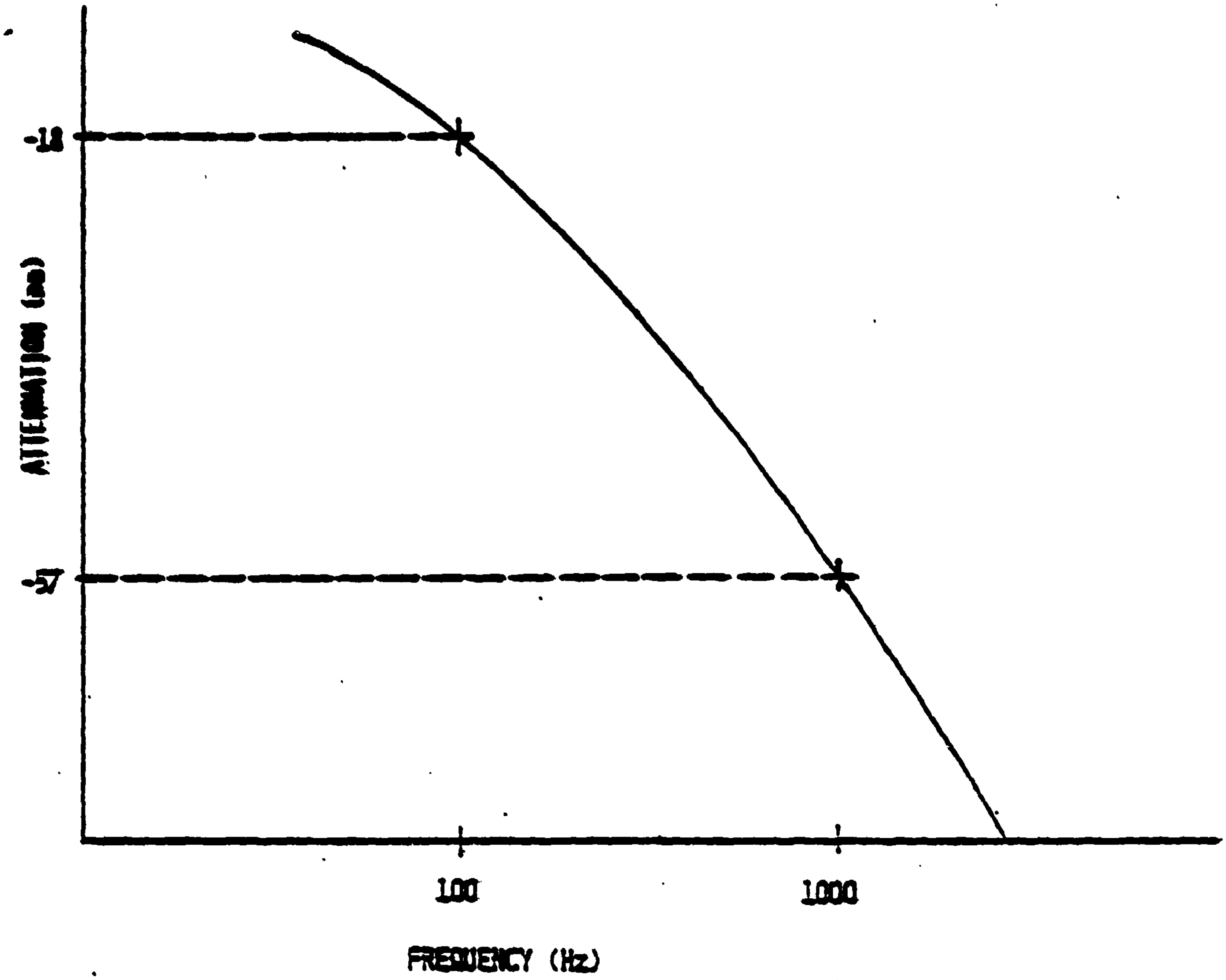
This provided for the analysis of the relative merits of cycle averaging and determined the minimum wait required after the beginning of each cycle to account for settling time. The frequency bandwidths shown are approximate and some overlapping may have to be accounted for in the processing as a price for thermistor and conductivity cell noninterchangeability. The channel widths are approximately 60 ms wide resulting in a data rate of approximately four measurement sets per second. The counter and the voltmeter serve temporarily as the XCTD receiver and processor. Therefore, in order to measure as many as ten cycles after a delay and provide enough time for the voltmeter or frequency counter to make a conversion, the channel width was expanded to approximately one second each. The XCTD circuit is continuously and asynchronously outputting the data in the order shown in Figure 3.0-2. The voltage across the 400Ω resistor R_{LO} is sampled, amplified, and fed to the voltmeter while simultaneously being converted to a frequency followed by a pulse of width equal to a predetermined number of cycles of the frequency, and fed to the counter after a predetermined delay. The same process follows with the conductivity cell (or $R\delta$ resistance decade), the 4 KΩ resistor R_{HI} and the thermistor (or R_T resistance decade). Upon a command from the operator the HP85 computer continuously addresses the counter and the voltmeter and looks for the Low Cal frequency. The frequency is determined from the pulse width knowing the cycle count (2, 4, 6, 8 or 10). Once found the frequency is stored for subsequent use. The conductivity channel is expected next, followed by the High Cal and Temperature channels. If these channels are not found in the correct order the computer deletes all previous channel information and begins another search for the Low Cal channel. All accepted frequencies are followed immediately by the storage of voltage data. Once the computer has received all four channels of data it proceeds with the processing of the data. Signal attenuation is shown graphically in Figure 3.0-3. The maximum frequency is approximately 1 kHz which is attenuated by 57 dB for 8500 ft. of wire. The output signal from the probe is approximately 12 VRMS. This results in a minimum signal at the surface of 0.017VRMS. At 100 Hz the surface signal amplitude is attenuated by approx. 18 dB and results in a 1.5 VRMS signal.



FOR 8500 FT #39:

a. 100 Hz ⟶ -18DB ATTENUATION
a. 1000 Hz ⟶ -57DB ATTENUATION

RANGE = 39DB

BT 2 CONDUCTOR WIRE SIGNAL ATTENUATION

FIGURE 3.0-3

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3.3 Calibration and Test Requirements

In order for the XCTD probe to make an accurate measurement of conductivity and temperature the characteristics of both the conductivity cell and the thermistor must be determined. These characteristics are determined by actually measuring the cell's and thermistor's in-circuit response under known conditions of conductivity and temperature. Effectively this is determining the measured resistance of the cell and thermistor at three discrete values of conductivity and temperature, respectively. To date, conductivity and temperature calibrations, and consequently, actual measurement profiles have been taken with one of the sensors simulated with a resistance decade box. During Phase II both salinity and temperature will be changed simultaneously in a controlled bath during calibration and testing of deployable units. The required setting of R_T is known approximately from previous tests or manufacturer's data for the thermistor. The same holds true for $R\delta$ knowing the approximate cell constant. Therefore, the calibration procedure, under program direction, involves the acquisition of extra temperature or conductivity data, ie. Low Cal, Conductivity, High Cal, Temperature, at three different levels. Once acquired, temperature (conductivity) can now be profiled by varying the temperature (conductivity) of the temperature (seawater) bath, while varying or holding constant the $R\delta(R_T)$ decade box. During both the calibration and measurement phases, measurements are continuously received from the Neil Brown Standard. The accuracy of the Neil Brown Standard is ±0.005°C for temperature and ±0.005 mmho/cm for conductivity. The measurements received during the calibration are stored by the computer and are incorporated in the calculations during the measure phase. The measurements received during the measure phase are used for comparison purposes only.

3.4 Data Processing and Software

The HP85 is the central component on the receiving end of the XCTD system in the lab configuration, and its functions are to:

- Manage calibrate and measure operations
- Input temperature and conductivity as measured by the Neil Brown Standard
- Input time interval data from the countar and convert to a frequency
- Input voltage data from the voltmeter
- Generate the circuit transfer function before each calibrate and measure cycle
- Calculate thermistor and conductivity cell sensitivities from calibration data
- Calculate actual conductivity and temperature based on measurement data and thermistor and conductivity cell sensitivities
- Provide a printout of:

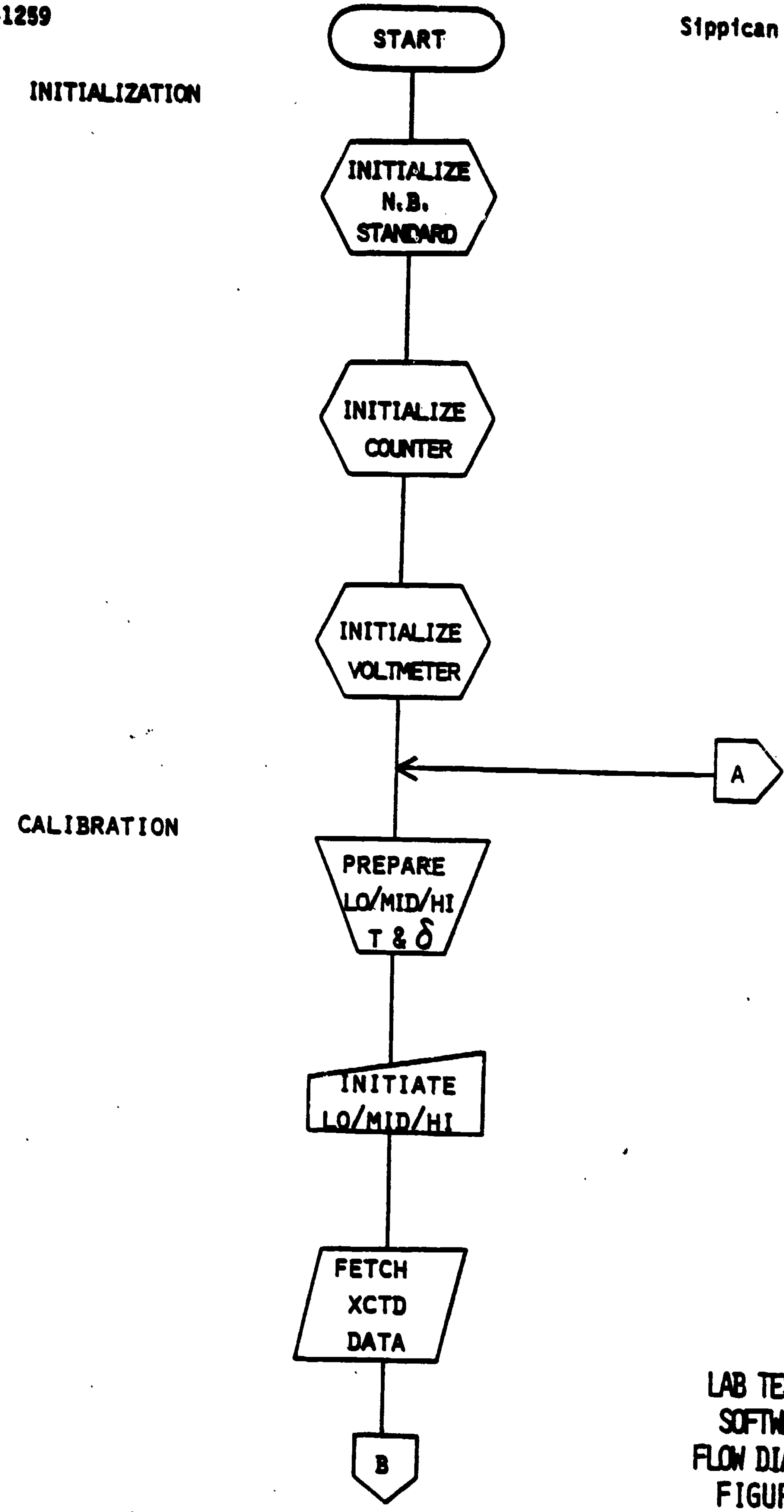
  Temperature and Conductivity as measured by the standard during calibration and in situ measurements

  Voltage and frequencies as measured during calibration and in situ measurements

  Resulting XCTD in situ temperature and Conductivity measurements

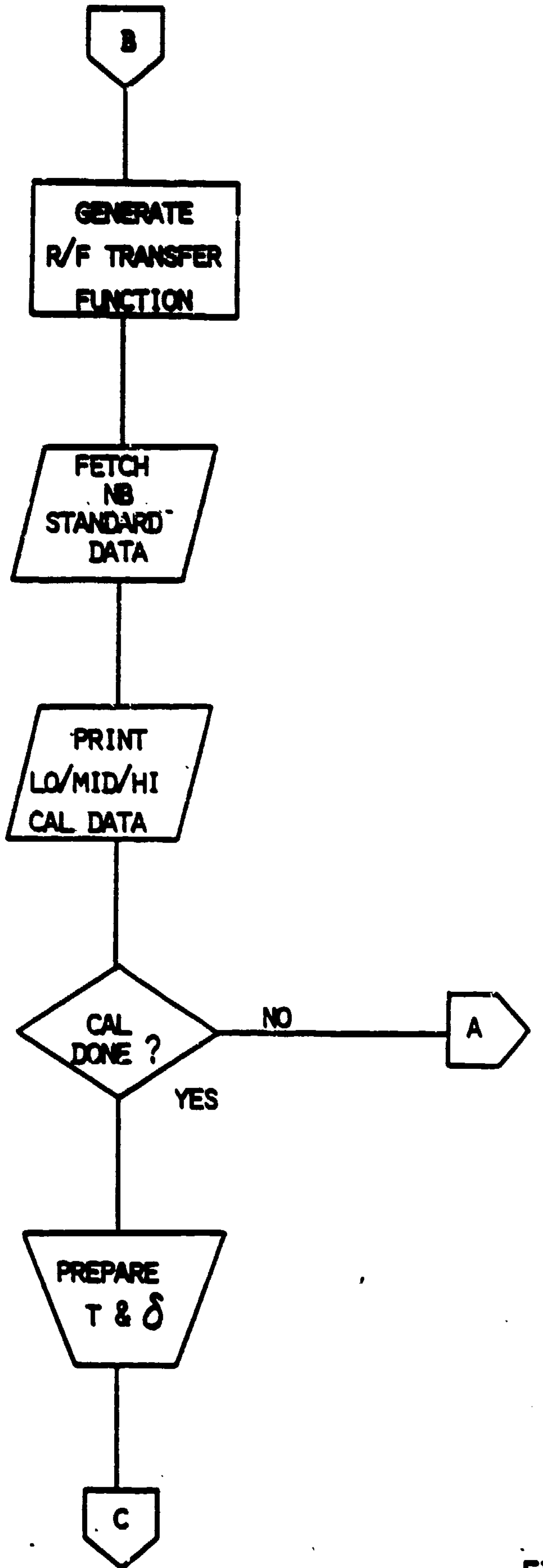
3.4.1 Initialization

A flow diagram of the software program is shown in Figure 3.0-3,A-D. The program begins with the initialization of the interfaces as required by the



LAB TESTING SOFTWARE FLOW DIAGRAM

FIGURE 3.0-3A



PRE-LAUNCH

FIGURE 3.0-3B

IN LAB MEASURE

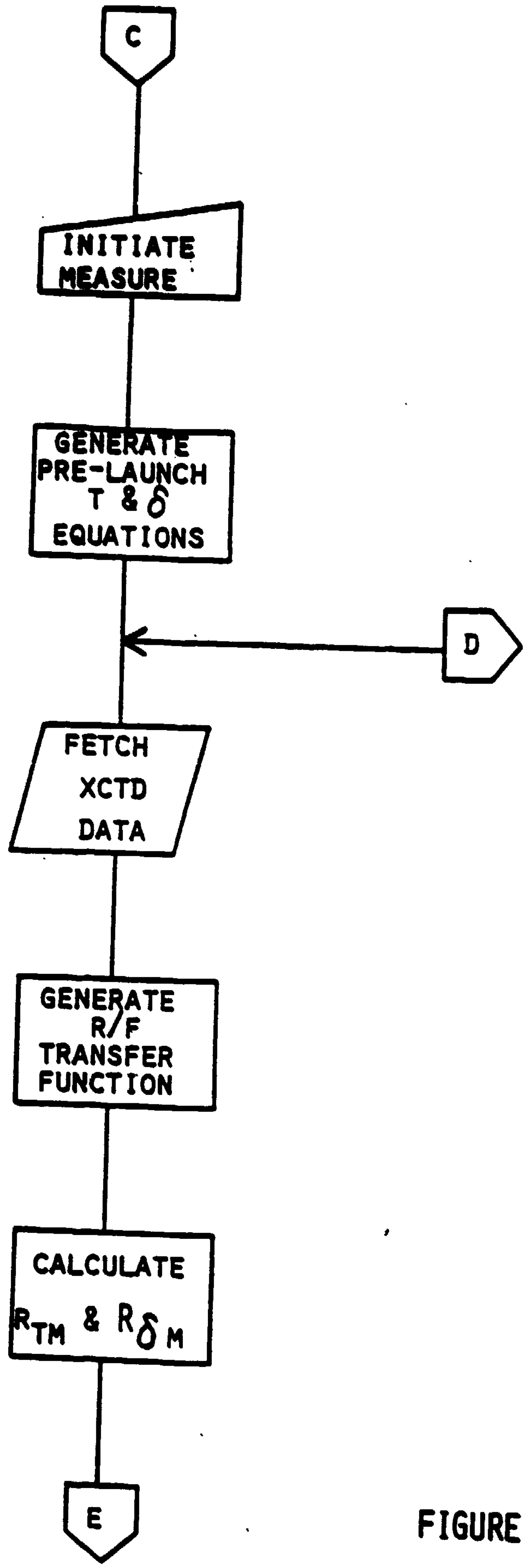


FIGURE 3.0-3C

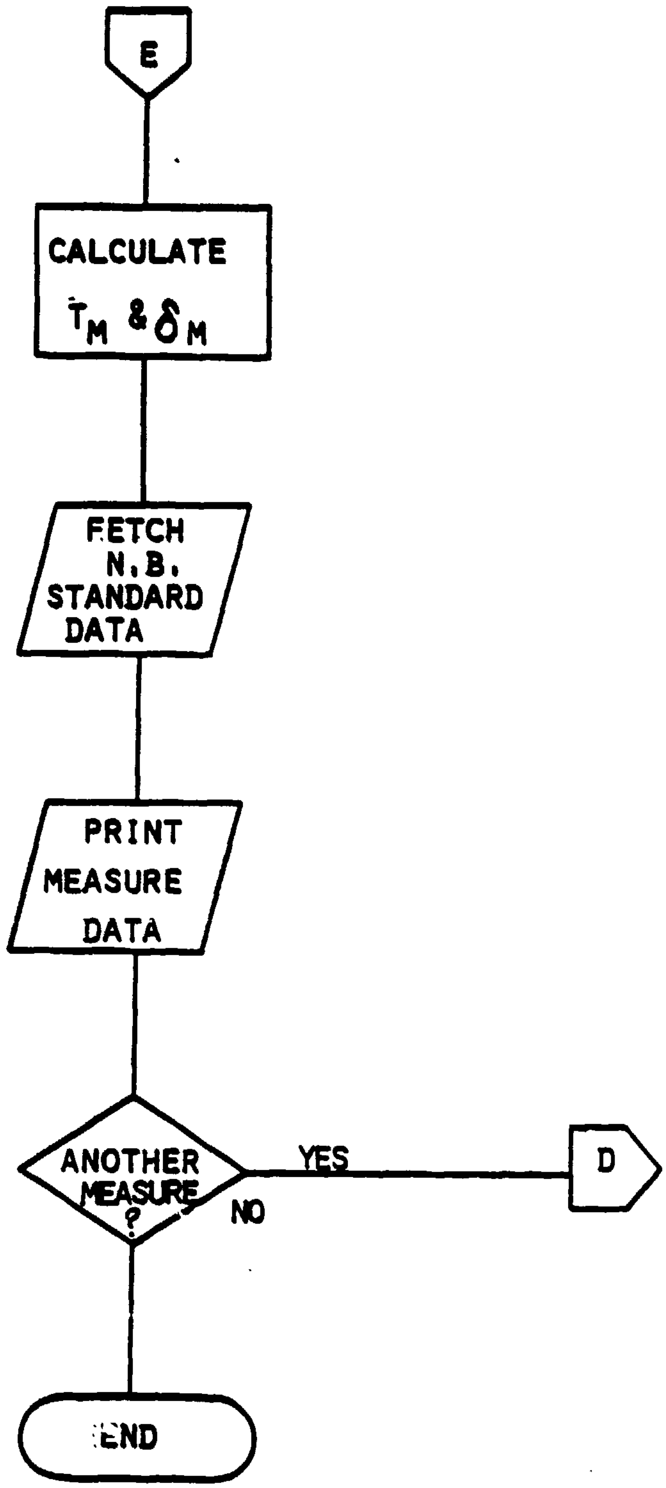

E
CALCULATE
$\bar{T}_M$ & δ_M
FETCH
N.B.
STANDARD
DATA
PRINT
MEASURE
DATA
ANOTHER
MEASURE
?
YES
NO
D
END

FIGURE 3.0-3D

HP85 and/or instruments. The Neil Brown Standard uses an RS-232 data link, which requires the setting of certain control bits. The counter requires trigger polarities, gate, and mode settings and the voltmeter requires scale and mode settings.

3.4.2 Calibration

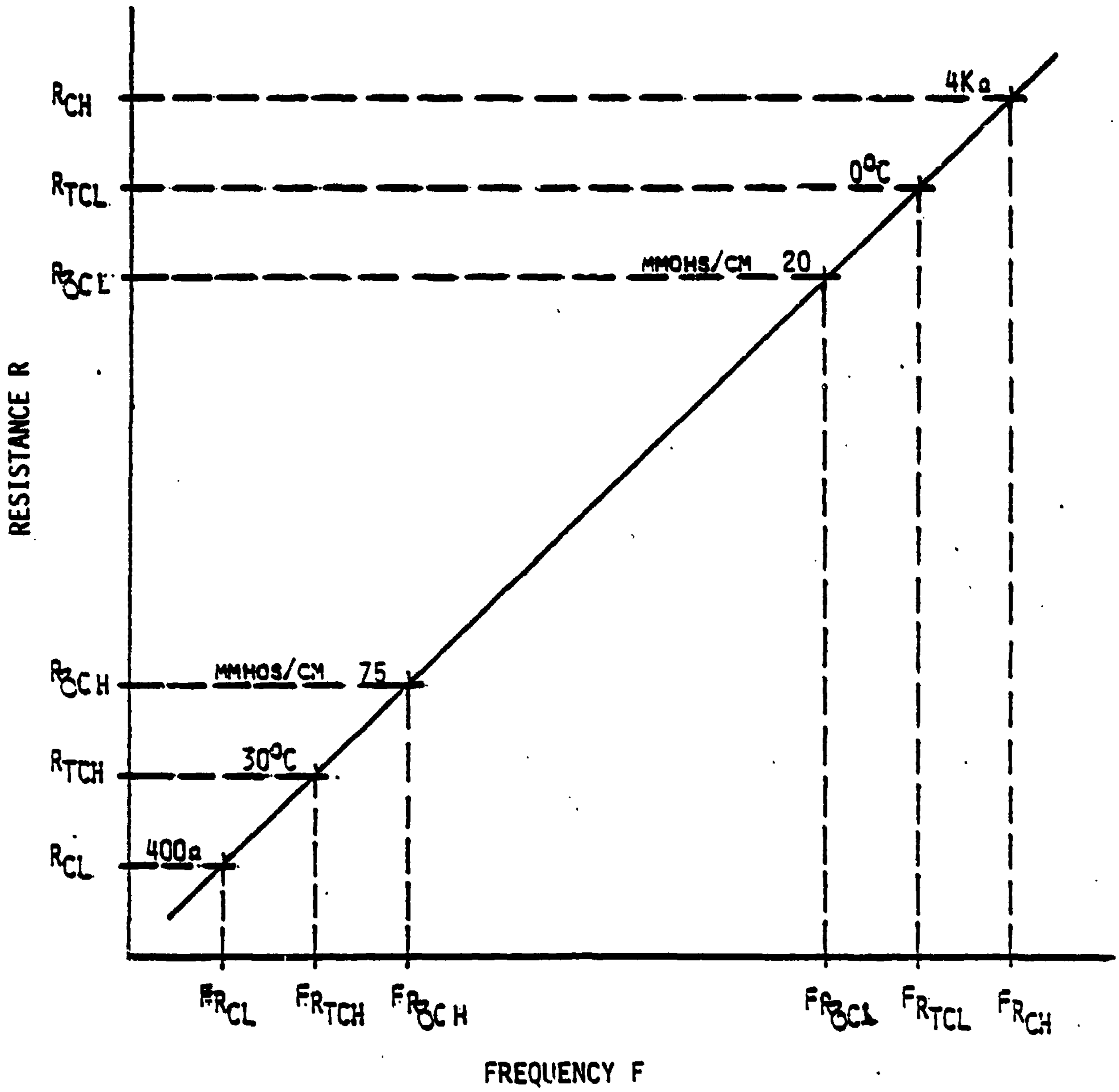
Following the instrument initializations the program requests a low, middle, or high calibration run and the XCTD and Neil Brown Probes are immersed in the low/middle/high bath. If simultaneous temperature and conductivity calibrations are being made, no decade box is required. When ready, required calibration level is input to the computer and the computer inputs the XCTD data, followed immediately by the calculation of R vs F and R vs V circuit transfer functions as determined from the R_{HI} and R_{LO} resistors and their resulting frequencies and voltages. This is shown graphically in Figure 3.0-4 along with the circuit transfer function. For simplification only frequencies will be used in the following descriptions, but voltages can be directly substituted for the frequencies. The applicable variables used in Figure 6 are defined as follows:

R_{CH}, F_{RCH} ... Cal High resistor (≈4KΩ, ±0.005%) and resulting output frequency.

R_{CL}, F_{RCL} ... Cal Low resistor (≈400Ω, ±0.005%) and resulting output frequency

R, F .... Calculated resistance R as determined from the measured frequency F

The circuit transfer function is derived for every calibration or measure cycle, thus compensating for any circuit variations such as amplifier gain, offset, drift, power supply fluctuation, etc. Next the program calculates



$$R = \frac{R_{CH} - R_{CL}}{F_{R_{CH}} - F_{R_{CL}}}\left(F - F_{R_{CH}}\right) + R_{CH}$$

XCTD "R/F" LINE EQUATION

FIGURE 3.0-

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the thermistor and conductivity cell resistances using the transfer function and the measured temperature and conductivity frequencies. The process is repeated for the remaining two calibration levels. This now introduces the remaining variables in Figure 6 as:

F_{RTCH}, R_{TCH} ... Frequency of temperature channel at Cal High and resulting calculated resistance

F_{RTCS}, R_{TCS} ... At Cal Middle

F_{RTCL}, R_{TCL} ... At Cal Low

$F_{R\delta CH}$, $R\delta_{CH}$ ... Frequency of conductivity channel at Cal High and resulting calculated resistance

$F_{R\delta CS}$, $R\delta_{CS}$ ... At Cal Middle

$F_{R\delta CL}$, $R\delta_{CL}$ ... At Cal Low

As a result of all the foregoing measurements each individual XCTD probe has now been "characterized" and with the thermistor and conductivity cell sensitivities assumed stable over time the following parameters are assumed never to change:

T_{CH}, R_{TCH}

T_{CS}, R_{TCS}

T_{CL}, R_{TCL}

δ_{CH}, $R\delta_{CH}$

δ_{CS}, $R\delta_{CS}$

δ_{CL}, $R\delta_{CL}$

The final process at each calibration level is a printout of actual temperatures and conductivities and corresponding voltages and frequencies. A sample calibration phase printout is presented in Figure 3.0-5. In summary, the calibration phase of the operation is to determine the temperature and corresponding calculated resistance and the conductivity and the corresponding calculated resistance at three different calibration levels. These parameters are stored permanently as probe characterizing data.

3.4.3 Pre-Lab Measurement

After the calibration phase the program is ready to initiate a measurement. Referring again to the flow diagram in Figure 3.0-3 the original calibration (or characterizing) data is used in the generation of pre-launch equations. This is shown graphically in Figure 3.0-6 the pre-launch equations are curve fitting equations, which use the probe characterizing data to generate functions of temperature and conductivity in terms of resistance. These equations are fixed for the life of the probe. Therefore, after the generation of the two equations the XCTD is ready to make measurements. At this point the variable temperature and/or conductivity bath(s) are prepared. If only temperature (conductivity) is to be profiled, the R_σ (R_T) decade box must be used to simulate the conductivity cell (thermistor).

3.4.4 Lab Measurement

A measurement begins on command from the operator. If the R_T (R_σ) decade box is used, the Low, Mid, and High Cal temperature (conductivity) will

```
*** LOW CAL ***

NEIL BROWN T AN S:

  Ts = 22.3215 *
  Ss = 21.2360

XCTD FREQUENCIES:

  Frch = 949.163
  Frcl = 186.711
  Frtcl = 524.849 *
  FrScl = 423.386

XCTD VOLTAGES:

  Vrch = 84.525
  Vrcl = 88.319
  Vrtcl = 82.393 *
  VrScl = 81.384
```

```
*** MID CAL ***

NEIL BROWN T AN S:

  Ts = 21.9828 *
  Ss = 58.7028

XCTD FREQUENCIES:

  Frch = 981.749
  Frcl = 118.346
  Frtcs = 318.382 *
  FrScs = 135.497

XCTD VOLTAGES:

  Vrch = 84.690
  Vrcl = 88.336
  Vrtcs = 81.336 *
  VrScs = 80.745
```

```
*** HIGH CAL ***

NEIL BROWN T AN S:

  Ts = 21.9690 *
  Ss = 73.3790

XCTD FREQUENCIES:

  Frch = 985.451
  Frcl = 111.858
  Frtch = 134.977
  FrSch = 133.831

XCTD VOLTAGES:

  Vrch = 84.759
  Vrcl = 89.343
  Vrtch = 80.694 *
  VrSch = 88.475
```

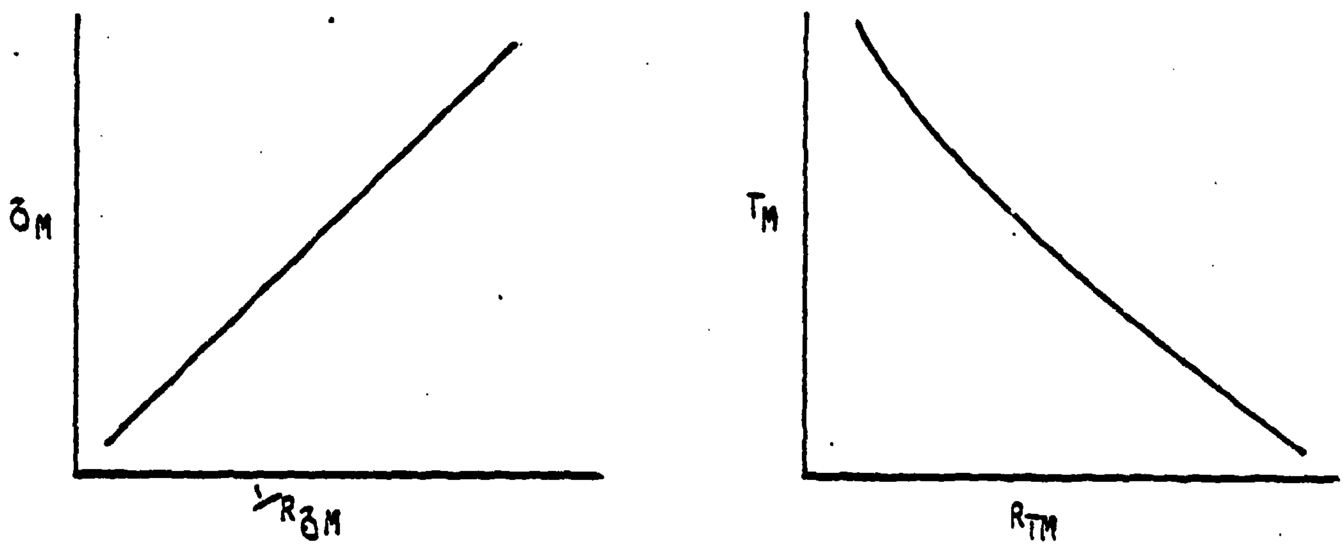
* IN THIS EXAMPLE ONLY CONDUCTIVITY (δ) IS BEING VARIED, TEMPERATURE (T) DOES NOT APPLY

CALIBRATION PHASE PRINTOUT
(CONDUCTIVITY)

FIGURE 3.0-5

AT PRELAUNCH

PRELAUNCH EQUATIONS ARE GENERATED BASED ON PROBE CAL-DATA:



CONDUCTIVITY EQUATION:

$$\delta_M = F[(\delta_{CH}, R_{\delta CH}), (\delta_{CS}, R_{\delta CS}), (\delta_{CL}, R_{\delta CL}), R_{\delta M}]$$

TEMPERATURE EQUATION:

$$T_M = F[(T_{CH}, R_{TCH}), (T_{CS}, R_{TCS}), (T_{CL}, R_{TCL}), R_{TM}]$$

PRELAUNCH EQUATIONS

FIGURE 3.0-6

GB
3/8/83

have to be input manually to satisfy the software requirements, while conductivity (temperature) data is received from the Neil Brown Standard. If simultaneous calibrations of temperature and conductivity were made, the measurements can be performed in the same manner and without the use of a decade box. The lab measurement begins with received data from the XCTD, followed immediately by the generation of the circuit transfer function using F_{RCH} and F_{RCL} measurements just as during calibration. Once the circuit transfer function is known the thermistor (or R_T) and conductivity cell (or $R\delta$) resistances are calculated as R_{TM} and $R\delta_M$, respectively. Next, the pre-launch equations are used to calculate the temperature and conductivity T_M and δ_M, respectively. Finally, the data from the Neil Brown Standard is received and a printout of the actual and measured temperatures and conductivities along with frequencies and voltages is printed. A sample measure printout is presented in Figure 3.0-7. This is for lab measurements only when conductivity and temperature errors are being measured.

3.5 Summary

Figure 3.0-8 is a block diagram summarizing the whole calibration and measurement process. The first step is to generate three discrete temperatures and conductivities and calculate their respective resistances via the R/F (resistance to frequency) transfer function, which is generated at every cal point. These six data pairs characterize the probe and are used to generate the pre-launch equations. The pre-launch equations are curve fitting equations, although to date a linear equation has been used for conductivity with good results. This equation utilizes only High and Low conductivity calibration data. Following pre-launch the probe is ready for the lab measurements and as shown in the block diagram, the transfer function is first calculated for each measurement followed immediately by the determination of the temperature and conductivity sensor's resistances. Finally, utilizing the pre-launch equations the temperature and conductivity is calculated.

```
*** MEASURE ***

NEIL BROWN T AND δ:

   Ta = 22.8270 *
   δa = 21.3000

XCTD FREQUENCIES:

   Frchm = 949.118
   Frclm = 106.713
   Frtm  = 524.838 *
   Frδm  = 423.442

XCTD VOLTAGES:

   Vrchm = 04.626
   Vrclm = 00.319
   Vrtm  = 02.393 *
   Vrδm  = 01.883

FREQUENCY BASED RESULTS:

   Tmf =  2.003
   δmf = 21.299

VOLTAGE BASED RESULTS:

   Tmv =  2.003
   δmv = 21.302
```

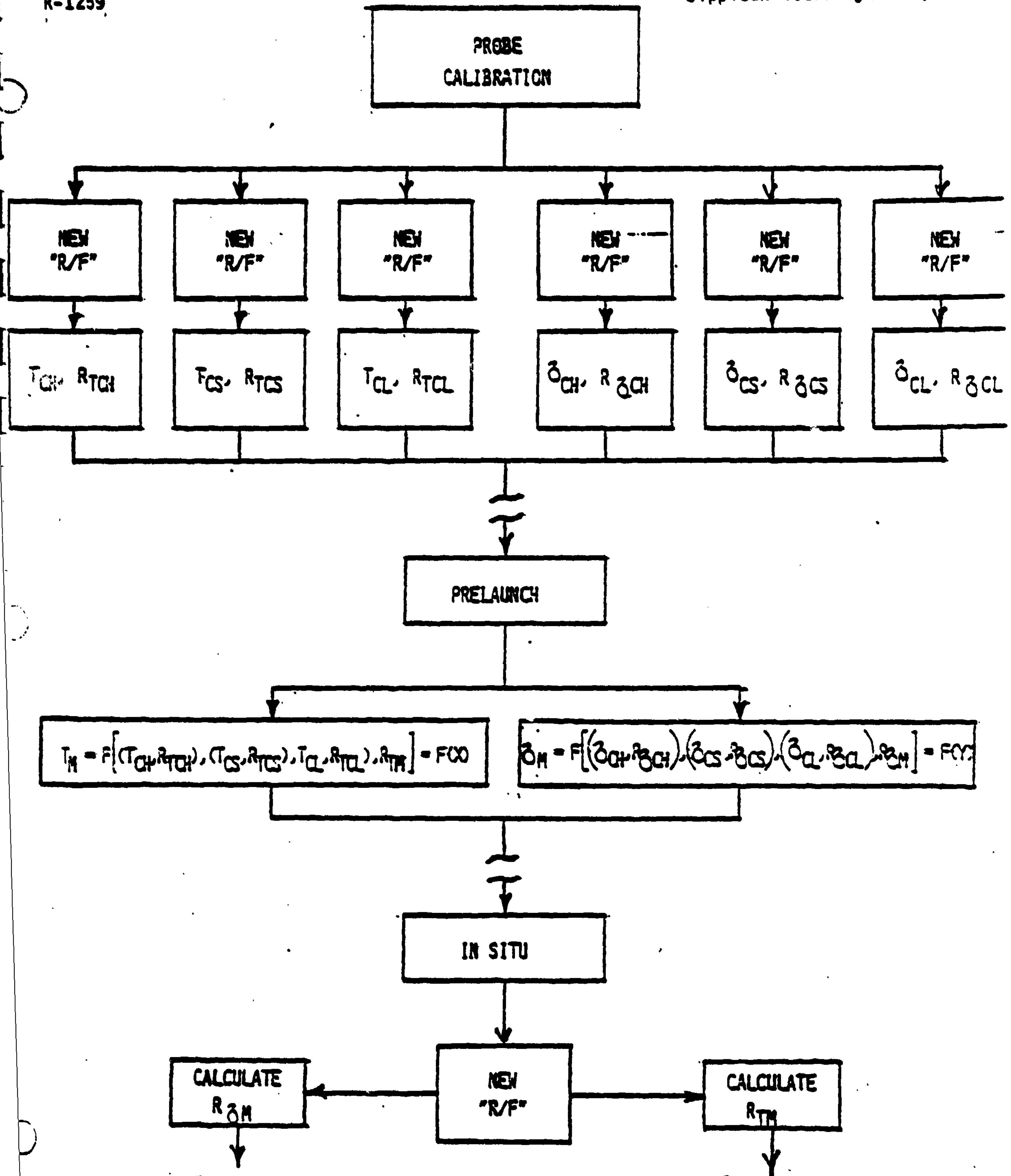
```
*** MEASURE ***

NEIL BROWN T AND δ:

   Ta = 22.8445 *
   δa = 28.6220

XCTD FREQUENCIES:

   Frchm = 956.434
   Frclm = 107.536
   Frtm  = 528.913 *
   Frδm  = 323.825

XCTD VOLTAGES:

   Vrchm = 04.563
   Vrclm = 00.323
   Vrtm  = 02.413 *
   Vrδm  = 01.383

FREQUENCY BASED RESULTS

   Tmf =  2.002
   δmf = 28.534

VOLTAGE BASED RESULTS

   Tmv =  2.002
   δmv = 28.618
```

```
*** MEASURE ***

NEIL BROWN T AND δ:

   Ta = 22.8870 *
   δa = 35.9410

XCTD FREQUENCIES

   Frchm = 961.003
   Frclm = 100.049
   Frtm  = 531.208 *
   Frδm  = 263.242

XCTD VOLTAGES:

   Vrchm = 04.585
   Vrclm = 00.325
   Vrtm  = 02.425 *
   Vrδm  = 01.081

FREQUENCY BASED RESULTS:

   Tmf =  2.008
   δmf = 35.761

VOLTAGE BASED RESULTS:

   Tmv =  2.001
   δmv = 35.934
```

* IN THIS EXAMPLE ONLY CONDUCTIVITY (δ) IS BEING VARIED, TEMP (T) DOES NOT APPLY

MEASUREMENT PHASE PRINTOUT (CONDUCTIVITY)

FIGURE 3.0-7



CALIBRATION/MEASURE
BLOCK DIAGRAM

FIGURE - - -

4.0 SYSTEM ERROR ALLOCATIONS

As mentioned previously the errors have been proportioned to three areas as follows:

1. Conductivity/Temperature
2. Probe Processing Electronics
3. MK 9 Data Recorder

Each catagory is allowed a maximum error of 0.01°C and 0.01 mmhos/cm.

4.1 Sensor Error Contribution

Sensor error contributions have been analyzed separately in terms of accuracy and stability. Each show the ability to meet or exceed the maximum allowable error.

4.1.1 Conductivity Sensor Error Contribution

The conductivity sensor or cell is a linear device with a measured cell constant of approximately 37.5/CM. The cell is a four electrode device, therefore, its stability is influenced only by the internal volume and not the electrodes. The volume can be changed in only two ways: Buildup of film within the walls of the cell and changes in volume due to expansion or contraction of the cell due to temperature changes. The coefficient of expansion is 32×10^{-7} in/in°C. Therefore cell constant changes which are per

$$K = L/A$$

for this type of cell are equivalent to that which produces approximately a 0.001 mmho error over 60°C of temperature change. Buildup of film within the cell would not occur since the cell is intended to be used only once and no contact with fluids are made following calibration at the factory until deployment.

4.1.2 Temperature Sensor Error Contribution

The temperature sensor is a glass encapsulated thermistor whose long term stability is dependent on its operating current and environmental exposure. The operating current is very small (approximately 43 microamperes) and is of course zero while in storage. Therefore, how well the thermistor is sealed in the glass over a long period will have the most influence on the thermistor's long term stability. During the years 1974 to 1975 the National Bureau of Standards tested 405 thermistors from 6 manufacturers. The bead in glass thermistors, which is the type selected for the XCTD application, exibited only a 0.00042°C per 100 days average drift in a constant 60°C temperature bath. This is equivalent to a temperature drift of 0.003°C in two years. Specifically, the Thermometrics thermistors showed a 0.00020°C per 100 days temperature drift, which is equivalent ot approximately 0.001°C in two years. Therefore, the 0.01°C allowable error will be attributable mostly to linearizing errors. Linearizing is performed in the MK 9 software using the three temperature calibration points and is accurate to better than 0.01°C over the temperature range. Self heating due to operating current is also well below the allotted sensor accuracy as described in Section 7.0.

4.2 Probe Processing Electronics

Overall circuit accuracy, independent of the thermistor and conductivity cell was determined. The test was performed both immediately and using the same characterization data, three days after calibration. Both decade boxes were used to simulate tha sensors during the calibration and measure phases. The conductivity decade was varied according to the following relationship:

$$R\delta = \frac{1}{\delta}(K) \times 1000$$

Where $K = 35.7\ cm^{-1}$ is the cell constant, S is equivalent conductivity in mmhos/cm and R_S is resistance in ohms. The temperature decade was varied during calibration but held constant during measure to investigate the magnitude of change due to varying conductivity. A three point calibration was performed for both temperature and conductivity to satisfy software requirements but only high and low cal data was used in the conductivity pre-launch equation. All results were based on output voltage measurements rather than frequency due to the relative non-linearity of the Voltage to Frequency Converter. Table I shows the resulting equivalent conductivity errors over a range of 20 to 75 mmhos/cm. The largest error occured at 65 mmhos/cm and is 0.006 mmhos/cm. The equivalent temperature variation over the whole range of conductivity was 0.003°C. Three days later the same test was run using the same characterizing data, ie., the calibration phase was not repeated. These results are also presented in Table I.

4.3 MK 9 DATA RECORDER XCTD INTERFACE

The XCTD interface in the MK 9 Data Recorder will be allotted one third of the overall system accuracy. The inaccuracies will be directly dependent on the inaccuracies of the system clock and jitter in the detector circuitry in the analog receiver section.

TABLE I
OVERALL SYSTEM ACCURACY

T °C	R_T Ω	δ mmho/cm	$R\delta$ Ω	T_M °C	δ_{M1} mmho/cm	δ_{E1} mmho/cm	δ_{M2} mmho/cm	δ_{E2} mmho/cm
2.0035	217.0	20.000	1785.0					
15.0005	1243.0	50.000	714.0	Calibration Phase. T is from measured data.				
29.9895	686.0	75.000	476.0					
2.0035	2174.0	20.000	1785.0	2.004	20.000	0.000	20.000	0.000
		25.000	1428.0	2.003	25.000	0.000	24.998	-0.002
		30.000	1190.0	2.003	30.001	0.001	29.999	-0.001
		35.000	1020.0	2.002	35.001	0.001	34.999	-0.001
		40.000	892.5	2.002	40.000	0.000	40.001	-0.001
		45.000	793.3	2.002	45.002	0.002	44.999	-0.001
		50.000	714.0	2.002	50.003	0.003	50.000	0.000
		55.000	649.1	2.002	55.001	0.001	54.998	-0.002
		60.000	595.0	2.002	60.001	0.001	60.000	0.000
		65.000	549.2	2.002	65.006	0.006	64.996	-0.004
		70.000	510.0	2.001	70.004	0.004	69.998	-0.002
		75.000	476.0	2.001	75.003	0.003	75.002	0.002

T... Equivalent temperature in °C as obtained from typical thermistor sensitivity data (decade box set at 2174 ohms during measure phase to represent 2.0035°C).

R_T.........decade resistance simulating T
δ..........equivalent conductivity at $R\delta$
$R\delta$........ decade resistance simulating δ
T_M........ resulting equivalent temperature
$\delta M_1, \delta E_1$... resulting equivalent conductivity and error, day 1.
$\delta M_2, \delta E_2$... resulting equivalent conductivity and error, day 4.

5.0 CIRCUIT STABILITY

Circuit stability was determined by independently varying amplifier gain and offset after the initial calibration phase. Resistance decade boxes were used in place of the sensors as in Section 3. Table II shows the results of varying the gain from the nominal of 15 to 10 and then to 20. The top of Table II shows the absolute readings at three different conductivities and temperatures. Circuit calibration was performed at a gain of 15 in this case, followed by measurements at the three different gain settings. The middle of Table II shows the absolute error as a result of the gain variation from nominal. Finally, the bottom of Table II shows the deviation of conductivity and temperature as a result of varying the gain from its nominal value. The results show that with only two exceptions the errors due to a gain change were less than 0.01 mmhos/cm and 0.01°C. A similar test was performed to determine variation with circuit offset. Table III shows the results in a format similar to that used in Table II. Here, calibration was performed at an offset of 0.0 volts and measurements were made at an adjusted offset of 0.30 volts and -0.30 volts. The results show that with only a few exceptions the error is less than 0.01 mmhos/cm and 0.01°C. Considering that the offset and gain were varied approximately 30 times greater than would be expected over the temperature range these errors are very conservative.

TABLE II

CIRCUIT GAIN STABILITY

GAIN	δ_L=20	δ_S=45	δ_H=65	T_L=2.004	T_S=15.001	T_H=29.989
10	19.996	44.984	65.019	2.005	15.000	29.982
15	19.999	44.987	64.990	2.003	14.999	29.987
20	19.996	44.981	64.981	1.998	14.981	29.986

ERROR

10	0.004	0.016	-0.019	-0.001	0.001	0.007
15	0.001	0.013	0.010	0.001	0.002	0.002
20	0.004	0.019	0.019	0.006	0.020	0.003

DEVIATION

10	-0.003	0.003	-0.029	-0.002	-0.001	0.005
15	0	0	0	0	0	0
20	-0.003	0.006	0.009	0.005	0.018	0.001

δ is in mmhos/cm

T is in °C

TABLE III

CIRCUIT OFFSET STABILITY

OFFSET	δ_L=20	δ_S=45	δ_M=65	T_L=2.004	T_S=15.001	T_H=29.989
0.30	19.998	44.995	65.005	1.998	15.000	29.991
0	20.001	44.991	65.002	2.004	15.001	29.987
-0.30	19.998	44.978	64.972	2.003	14.999	29.978

ERROR

0.30	0.002	0.005	-0.005	0.006	0.0012	-0.002
0	-0.001	0.009	-0.002	0.000	0.000	0.002
-0.30	0.002	0.022	0.028	0.001	0.002	0.011

DEVIATION

0.030	0.003	-0.004	-0.003	0.006	0.001	-0.004
0	0	0	0	0	0	0
-0.30	0.003	0.013	0.03	0.001	0.002	0.009

δ is in mmhos/cm

T is in °C

6.0 SYSTEM MEASUREMENT ACCURACY

During the course of the XCTD circuit development a number of both temperature and conductivity profiles were made to determine the relative accuracy of each. At no time were conductivity and temperature simultaneously profiled but a reasonable approximation was made by simulating one of the sensors with a resistance decade.

6.1 Conductivity

Using the laboratory procedures described in Section 3 measurements of temperature and conductivity were individually made and accuracies based on the Neil Brown Standard were determined. Table IV shows the results of a measurement made in one time period, ie., immediately following the calibration phase. All the measurements were made in approximately a two hour period. Temperature was simulated with a decade box while conductivity was a real measurement. During the conductivity profile the decade box resistance was held constant at that resistance representing 2.000 C. Two outputs, frequency and voltage, are listed and the conductivity accuracies as a result of each are also included. The conductivity range was from approximately 20 to 75 mmhos/cm.

6.2 Temperature

A temperature profile was generated over a temperature range of approximately 2°C to 30°C. Calibration data was simultaneously taken during the profiling procedure at low, mid (15°C), and high temperature. A decade box substituted for conductivity during the procedure and was held constant during the entire profile. Table V lists the results of the test.

TABLE IV

CONDUCTIVITY ACCURACY TEST

δ_{nb}	δ_{mv}	δ_{mf}	E_v	E_f
20.912	20.913	20.920	-.001	-.008
27.576	27.581	27.596	-.005	-.020
34.008	34.016	34.017	-.008	-.009
40.244	40.254	40.259	-.010	-.015
46.295	46.300	46.274	-.005	-.021
52.150	52.159	52.148	-.009	+.002
57.850	57.862	57.840	-.012	+.010
63.457	63.470	63.452	-.013	+.005
68.759	68.771	68.750	-.012	+.009

δ_{nb}.....Conductivity as measured by the Neil Brown Standard. Units are in mmhos/cm.

δ_{mv}.....Conductivity as measured by the XCTD as per voltage measurements. Units are in mmhos/cm.

δ_{mf}.....Conductivity as measured by the XCTD as per frequency measurements. Units are in mmhos/cm.

E_v .....Resulting error per voltage measurements in mmhos/cm.

E_f .....Resulting error per frequency measurements in mmhos/cm.

TABLE V
TEMPERATURE ACCURACY TEST

T_{nb}	T_{mv}	T_f	E_v	E_f
0.0045	-0.001	-0.002	0.006	0.007
2.0105	2.006	2.007	0.005	0.004
4.0025	3.999	4.001	0.004	0.002
6.0020	5.997	5.997	0.005	0.005
8.0045	8.001	8.002	0.004	0.003
10.0030	9.996	9.999	0.007	0.004
12.0045	12.002	12.004	0.003	0.001
14.0040	14.000	14.000	0.004	0.004
16.0030	15.997	15.999	0.006	0.004
18.0025	17.998	17.999	0.005	0.004
20.0010	19.996	19.997	0.005	0.004
22.0010	21.997	21.998	0.004	0.003
24.0000	23.995	23.995	0.005	0.005
25.9980	25.993	25.994	0.005	0.004
27.9955	27.991	27.993	0.005	0.003
29.9930	29.989	29.989	0.004	0.004

T_{nb}.....Temperature as measured by the Neil Brown Standard. Units are in °C.

T_{mv}.....Temperature as measured by the XCTD as per voltage measurements. Units are in °C.

T_f .....Temperature as measured by the XCTD as per frequency measurements. Units are in °C.

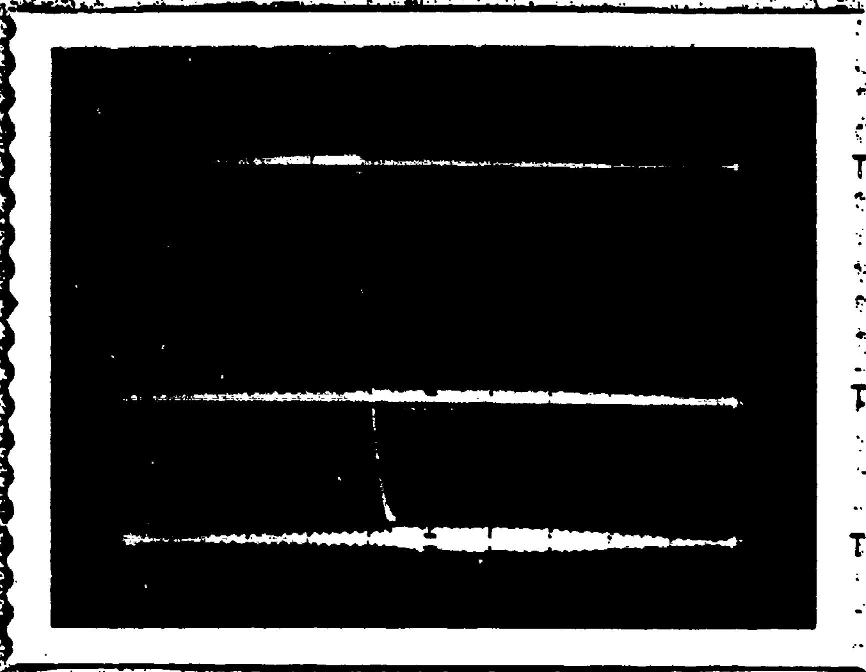
E_v .....Resulting error per voltage measurements in °C.

E_f .....Resulting error per frequency measurements in °C.

7.0 THERMISTOR TYPE

Two thermistors, a Fenwall type GB31M2 and a Thermometrics type P20BA102M, were used in the cab tests. Both thermistors are glass encapsulated noninterchangeable devices with tolerances specified at ±20% from the nominal resistance of 1K at 25°C. The Thermometrics thermistor was used in the test which produced the data shown in Table V, page 6-3. A linearization equation and three point calibration is used to obtain the specified accuracies. The time constant, which is the time required for the thermistor to change its own temperature 63% of the way from its original value to the value impressed upon it in a step change, was experimentally found to be 200 msec for the Fenwall type and 20 msec for the Thermometrics type. Figure 7.0-1 shows a scope trace of the response of the Thermometrics thermistor. The thermistor was taken from air temperature, the T_{High} reference line on the trace, and plunged into a temperature bath at 2.30°C, the T_{Low} reference line. The $T_{63\%}$ line is the 63% point mentioned above. The stability of the thermistors is insured by the glass encapsulation as described in Section 4.1.2. Both thermistors meet the stability requirements, and with the smaller time constant, the thermometrics thermistor also meets the required speed. A time constant of 20 msec means that in 5 time constants or approximately 100 msec, a step change in temperature is fully sensed by the thermistor.

The self heating of the thermistors were experimentally found to be approximately .002°C for the Fenwall type and .005°C for the thermometrics type. The above values, which refer to worst case conditions (lowest temperature and highest resistance), are below the allotted sensor accuracy. The current through the thermistor, approximately 43μA, is relatively small. The typical amount of power across the thermistor will be approximately 2μW and around that power range the self heating for the thermometrics thermistor is approximately .002°C. The Fenwall thermistor, which has a diameter of .060," and the Thermometrics thermistor, with a diameter of .020" will both be tested more extensively for accuracy and overall applicability in Phase II.



THERMISTOR TIME RESPONSE

FIGURE 7.0-1

8.0 CONDUCTIVITY CELL

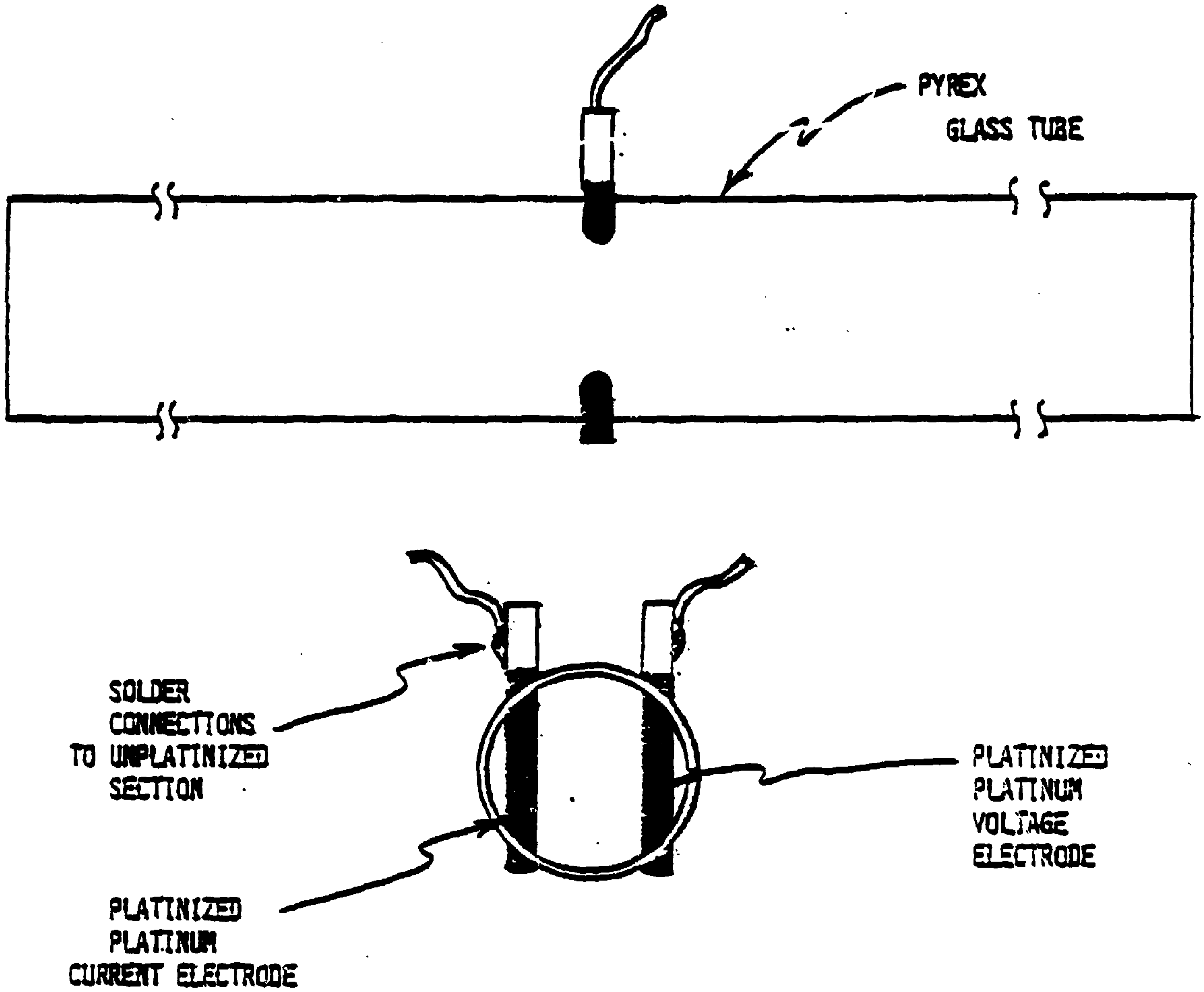
The conductivity cell is of the four electrode type utilizing a Pyrex glass tube and platinized platinum electrodes. The cell configuration as advised by Neil Brown of Neil Brown Instruments, Inc. is pictured in Figure 8.0-1.

8.1 Configuration

The pyrex glass tube is approximately 8 inches in length with an I.D. of 0.157 inches and an O.D. of 0.24 inches. Inside the tube at its midpoint is a current electrode C1 and a voltage electrode V1. The remaining current electrode C2 and voltage electrode V2 are outside the cell. They will consist of wires within a protected flooded chamber within the probe body. The cell will reside at the center of the probe along its axis surrounded by the wire spool and electronics. During deployment water will enter the cell through an opening in the zinc nose and exit at the tail with the dereeling wire.

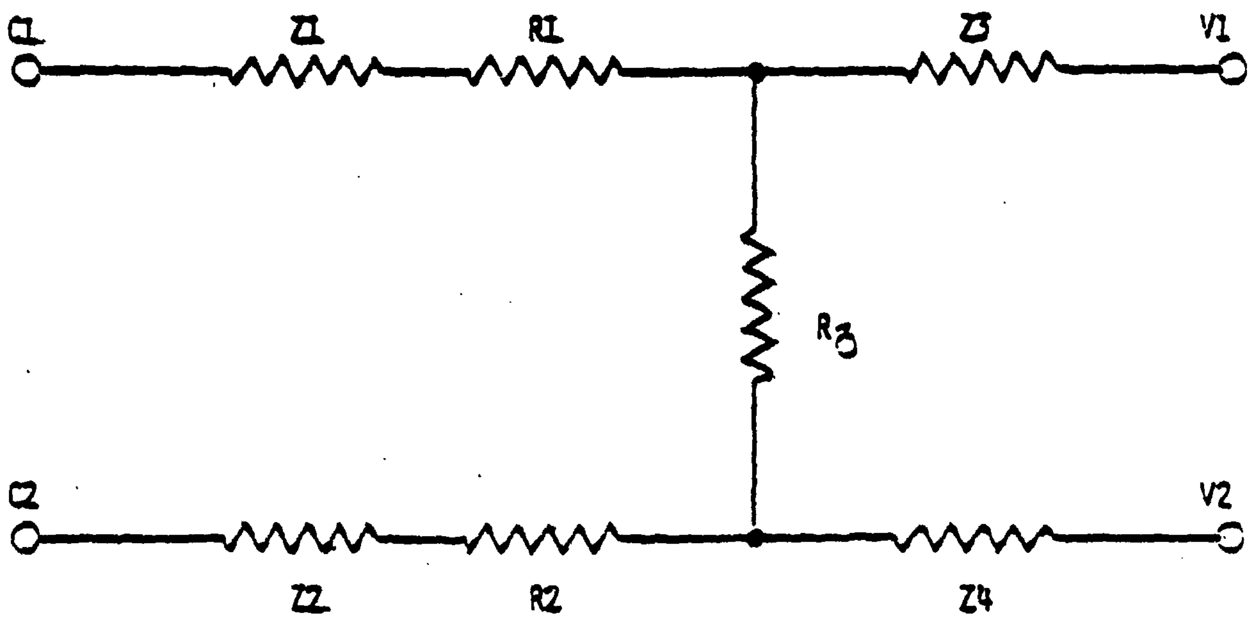
8.2 Operation

A schematic representation of the conductivity cell is shown in Figure 8.0-2. The cell functions as a four terminal resistor where a constant amplitude current AC square wave is applied to C1 and C2. The polarization impedances Z2 and Z4, which are a result of chemical reactions as the electrodes have no effect on the measurements since the voltage terminals are connected to a high impedance device. Similarly Z1 and Z2 have no effect since they are not part of the measurement circuit. Impedances R1 and R2 are the effective resistances of the seawater between the current electrodes and the voltage electrodes and are also not part of the measurement circuit. Therefore, this four electrode configuration is capable of accurately measuring the resistance of the seawater R6 independent of any unwanted series resistances.



XCTD CONDUCTIVITY CELL

FIGURE 8.0-1



C1,C2...CURRENT ELECTRODES

V1,V2...VOLTAGE ELECTRODES

Z1-Z4...POLARIZATION IMPEDANCES

R_1,R_2...RESISTANCE-CURRENT ELECTRODE TO THAT POINT IN SEAWATER WHERE VOLTAGE IS MEASURED

R_3... RESISTANCE CONDUCTIVITY CELL

XCTD CONDUCTIVITY CELL
MODEL

(4 ELECTRODE CONFIGURATION)

FIGURE 8.0-2

8.3 Electrode Platinization

The electrodes used in the conductivity cell are made of solid platinum. Platinum is a noble metal, and therefore, is ideal in a saltwater environment, but its cost is very high and warrants efficient utilization. Electrodes also require a large surface area to be effective in passing an AC signal with the minimum of loss. This is equivalent to a large effective series capacitance in series with the seawater resistance. Therefore, in order to increase surface area without adding material, the electrodes are platinized using a solution of 0.3% platinum chloride and 0.025% lead acetate in water. This creates a coating of platinum black which is extremely porous and increases the effective surface area of the electrodes. The electrodes are immersed in the platinizing solution and a small DC current is allowed to flow alternately between them at fifteen to twenty second intervals. Alternatively, both electrodes can be platinized simultaneously without current reversal by immersing both electrodes in the solution with a third electrode, which is made of stainless steel, nickel, or platinum. The third electrode would be the positive terminal. The platinizing continues until a uniform black matte finish appears and usually takes just a few minutes depending on the current density.

9.0 REMAINING DESIGN AREAS

There are two subsystem design functions that must be addressed. These are probe characterization or calibration data storage and custom LSI technology conversion of the probe electronics.

9.1 Calibration Data Storage

All XCTD probes are characterized with 6 pairs of calibration data. These are comprised of three pairs of temperature vs. frequency and three pairs of conductivity vs. frequency data. This data can be stored on cassette tape, which would be packaged one in each case of 12 probes. The tape would contain not only the calibration data but would provide the storage medium for the measured data. Another approach would be to use a bar code, which would be printed on each probe canister and provide an "intelligent" launcher or launcher modification kit, which would automatically read calibration data prior to launching of the probe. Another approach is an expendable prom or magnetic card which could be implemented in the MK9 processor. One prom or card would be supplied with each case of XCTD probes. For the present, system calibration data will be entered via the HP85 keyboard by the operator just prior to launching of the XCTD probe. The calibration data will be supplied with each probe.

9.2 Custom LSI Integrated Circuit

The XCTD circuit can be converted to a single custom integrated circuit. The circuit can be broken down into a number of functions, i.e., basic timing, multiplexing, voltage to frequency conversion, etc., all of which can be functionally incorporated on a single wafer containing analog and digital circuitry. The larger timing capacitors would be external to the custom I.C. In large quantities customizing of the circuit would reduce costs both in hardware and in assembly and test.

10.0 ALTERNATIVE APPROACHES

Sippican has considered various alternative approaches to the conductivity measurement problem. These approaches have been attempted previously by the named authors. Only a few though show any adaptability to expendables. They are:

1. Concentric cylinders, one containing standard seawater and the other sample seawater.

   Lawrence C. Murdock

   Westinghouse Electric Corp.

2. Free falling probe containing a chamber with a small opening to admit seawater. Inner and outer electrodes are used to measure the conductivity.

   Michael C. Gregg
   S. Cox

   United States of America as represented
   by the Secretary of the Navy

3. Four electrode conductivity sensor for moored sensor chains.

   Robert B. Sudar
   Edward L. Lewis
   Albert W. Koppel

   Canadian Patents & Dev. Ltd.

4. Saline delay line.

Albert Benjaminson

Ocean Search, Inc.

5. Dual needle conductivity cell.

Arthur M. Pederson

Applied Physics Laboratory

The first three approaches named above are mechanically complex and would be expensive for an expendable. The saline delay line while appearing simple enough mechanically, does not lend itself to a simple self calibrated circuit. The thermistor, which must work with the conductivity cell is a resistive sensor. It is desirable then to have a conductivity cell which is also resistive. A resistance measurement is the easiest, and therefore, least expensive to implement. The dual needle approach by Pederson is a resistive sensor, but it is not a four electrode configuration. This sensor is designed for use in a stratified tank as a reference sensor. The stability of a two electrode cell is not at all good since polarization resistance and changes thereof cannot be calibrated out in an expendable in a practical manner. The cell must be sta[illegible] and the sensitivities independent of polarization resistance. This is achieved only in a four electrode cell. The cell which Sippican has built and tested under the consultation of Neil Brown of Neil Brown Instruments, Inc., has to date demonstrated the capability of being constructed at a relatively low cost, shown repeatability in measurements, is resistive, and is expected to be stable since it uses four electrodes which are only immersed during calibration and deployment.

11.0 COST

A material breakdown of the XCTD components, manufacturing cost and calibration/test has yielded a sell price, based on 5,000 manufactured units/year, of $180.00 each.

12.0 SCHEDULE

Attached is a schedule which shows past and future development and manufacturing milestones for both the XCTD and deckgear programs.

APPENDIX B

R-2104

XCTD SEA TEST REPORT

January 4, 1988

Prepared by: Randall Elgin
Randall Elgin

Approved by: R Lancaster
Richard Lancaster

I. INTRODUCTION

On September 12 and November 19, 1987, the XCTD Program held 2 sea tests off the coast of Bermuda. These tests were conducted out of the Bermuda Biological Station aboard the R/V Weatherbird.

The following report describes the equipment, set-ups and procedures for all pre, during and post test related activities. This report documents our accumulated knowledge about the necessary procedures for producing XCTDs.

II. SYSTEM CONFIGURATION

A. PROBE CONFIGURATION

The Top Drawing List for the XCTD Probe is Drawing No. 302581, Rev 2.

1. MECHANICAL

Mechanically the XCTD probe is built almost as called out by the Top Drawing List. Those changes that have been made are for isolation of the zinc nose from the conductivity cell. The ground strap has been removed and the conductivity cell assembly changes are described below:

a) the two inner electrodes were fastened to the conductivity cell with a cyanoacrylate adhesive instead of the former heat shrink tubing approach. This procedure was used due to the fact that a suitable non-adhesive heat shrink tubing has not been found.

b) the thermistor was inserted through one of the inner electrodes instead of through its own hole in the glass. This step was incorporated to reduce manufacturing costs associated with glass drilling.

2. ELECTRICAL

The circuit used in the probe corresponded to Schematic 303155 Rev. 8 (see Appendix). The same electrical configuration was employed in the September and November Sea Tests.

The major difference between this electrical configuration and any former configuration was the multiplexing scheme of sampling/transmitting to eliminate the presumed interaction between the BT wire signal and the conductivity cell. The probe was modified to sample data from the sensors for 32 msec and then transmit this data as a frequency during the next 32 msec. This was accomplished by disabling the V/F during sampling and forcing the drivers to the positive or negative rail, which ever is closest to the DC value of the signal during transmission.

Two other changes included in this revision are a high pass filter after amplification and the addition of two resistors to ground between the conductivity cell capacitors and the multiplexor to dissipate the common mode and differential bias currents.

B. DECK GEAR CONFIGURATION

1. SEPTEMBER SEA TEST

The deck gear used in September most closely resembles the latest version of the Neil Brown Board, Drawing #302955 Rev 1. For this test several hardware changes not included in the schematic were made to accommodate the pulsed transmission of the probe. A marked up version of this schematic is included in the Appendix. These changes were as follows:

a) The clock frequency was increased from 1.5 MHz to 3.0 MHz by using the U30 pin 6 output instead of pin 9.

b) The Low Frequency Detector was modified to asynchronously load into the U27 counter 129 instead of 156.

*Note: For completely unknown reasons loading 128 into this counter causes the CO/ZD to intermittently occur. Just don't try to load 128 into this counter.

Also the U24 Q output was tied to the U27 CI/CE (formerly tied to ground) to prevent U27 from producing additional CO/ZDs after the first CO/ZD.

The W3 jumper was located at D.

c) The 60 msec Clock circuitry was altered to make it a 62.8 msec Clock. This was done by changing the number loaded into the U28 counter to 184 for LOCAL, COND & HICAL and 136 for TEMP.

d) The Period Counter was modified to count 2 periods. This was done by connecting U20 pin 7 across the W1 jumper. U20 pin 10 was used to initiate the BUSY signal (formerly done by pin 9).

For the November sea test the deck gear was redesigned to eliminate the attribute of looking for and syncronizing on the LOCAL frequency (see Schematic I). Since the ordering of the frequencies for data reduction is done at a higher level (in the computer), any checking for order at a lower level is redundant and in the event of not recognizing LOCAL wasteful since it prevents the acquisition of the following three frequencies. The deck gear was therefor redesigned to recognize frequencies and quiet times, and whenever a frequency is present, count it.

The schematic for the redesigned deck gear is included in the Appendix of this document.

3. ANALOG TAPE DATA ACQUISITION

a) SEPTEMBER SEA TEST

Output for the analog tape data was taken after the pre-amp and high and low pass filters at the front of the Neil Brown deck gear. This point was hard wired to an available output at the back of the MK9. From there it was cabled to two tape recorders and recorded simultaneously on both machines.

b) NOVEMBER SEA TEST

On the redesigned deck gear the analog signal was taken immediately after the isolation amplifier. This signal was put through a buffer and hard wired to an available output at the back of the MK9 recorder. From there it was cabled to a single tape recorder input.

C. SOFTWARE REVISION

A few revisions were made to the software to compliment the deck gear hardware changes:

With the increase in clock frequency and changing of the number of periods for which the probe frequency is counted, the formula to convert the number latched to frequency becomes

$$\text{frequency} = 6000000 / \text{number latched}$$

The frequency range for LOCAL was modified to be 200 to 350 Hz.

The addition of the two resistors to ground between the conductivity cell capacitors and the multiplexor form a parallel resistance to the conductivity cell that has to be removed in the software. The algorithm to do this is part of all the programs on the VAX and the test programs used by the HP85.

One additional software change was made just for the November sea test because of a problem encountered on the September sea test. The MK9RV3 program was modified so that if the IEEE data transfer is interupted, any data already obtained is saved.

III. PROBE BUILD AND QUALITY CONTROL

A. PROBE ASSEMBLY PROCEDURE

The assembly of the probes was the same for the September and November batches.

The boards were loaded by Lisa and Charlene in the Engineering Lab and tested with very little fall out (see Section IIIB). A small cut in one of the lands and two jumpers were required on each board due to an engineering and drafting error. This fix was done during loading.

Batteries were assembled and potted in the Engineering Lab. Four 6V batteries were soldered in series to provide +12V, -12V and common. They were then potted in a form that would allow for easy insertion into the battery cavity in the zinc nose and a thru-hole for the conductivity cell. Out of 28 unpotted battery assemblies, three sets failed before potting, and another three failed after potting. The three unpotted units could be made to work by vigorous twisting and pulling of the wires. The three potted units indicated open circuits in one of the legs of the bipolar supply.

Assembly of the conductivity cell was done in the lab. The electrodes were cemented to the cell quickly and without problems. Inserting the thermistors into the tiny holes in the electrodes proved troublesome for the first few units, only one out of five made it alive. After getting used to the procedure, the assemblers completed the remaining 25 units with only one additional failure.

The boards were rolled and inserted into the XCTD spacer. The conductivity cell was put in place and the battery leads, conductivity cell, and spacer electrodes were soldered to the board. This assembly was tested.

Eleven probes were potted. There were no 'leakers' or wires that the potting failed to cover completely. After the potting had set, one unit had a broken BT wire which was repaired. Another unit had only one BT wire yet proved to be useable.

B. ELECTRICAL TESTS

After being loaded the boards were bench tested in the unrolled condition, with an external power supply and resistors to simulate the thermistor and conductivity cell. The output was checked at the drivers.

Testing of the loaded boards showed that one board had a faulty component and two boards had transposed components. These were easily repaired.

After rolling, inserting and connecting all wires to the boards the probes were tested again. A resistive network was still used for the conductivity cell: a resistor was placed between the outside electrodes and the test points to the inside electrodes still accessable at the edge of the PC board. The probe was turned on with a wet paper towel across the turn on electrodes. The output was checked at the end of the BT wire.

The results of this testing were that only 5 out of 27 boards successfully survived the rolling process. Some of these failures were unique to this particular build. The small cut on the board mentioned earlier would sometimes close when the board was rolled up, rendering the board inoperative. Approximately 6 boards failed in this manner. These boards were reworked until only one unit was unrepaired.

C. RECOMMENDATIONS FOR FUTURE BUILDS

The problems incurred during rolling up the PC board should be addressed. Either another type of flexible board should be used or the circuit should be built upon rigid PC material in a manner such as XCP. The present layout of the circuit subscribes largely to the procedures that Rogers Corp. recommends for its Flex products.

The batteries requires a more reliable assembly procedure. Currently we use a can-type battery assembly which might allow the individual cells to separate upon stress or heat. Perhaps a heat-shrink type packaging scheme might be more suitable for our application.

D. CALIBRATION

The following description of the calibration procedure was used for the September and November builds. This procedure follows the description for XCTD calibration Requirements documented in OM-8528.

1. CALIBRATION CONFIGURATION

a) BATH DESCRIPTION

The Guildline Model 9374 Constant Temperature Bath was set up in the Engineering Wet Lab. The set up included a 10' 1/2" copper tubing heat exchanger laid inside the perimeter of the bath. Water from the bath was pumped through the heat exchanger by a 15W Aquamaster aquarium pump. The output of the heat exchanger connected via a flexible plastic tube to a fitting on the probe holding fixture which directed this stream of water at the nose of the probe. The bath water was filtered by a standard external cotton fiber aquarium filter with a 15W Aquamaster pump and 3 siphons. Marine Mix was added to Marion tap water to obtain sea water heated to 35 C overnight. The following day the bath was set at 30 C.

b) NBIS INSTRUMENT

The Neil Brown CTD Standard #2 was used. This instrument was calibrated by Neil Brown Instruments in November 1986. The data from this calibration is as follows:

		Average Error Tol=+0.005
	30 C	-0.0047
Temperature	15 C	+0.0005
	0.5 C	-0.0035
	55 mmho/cm	+0.0237
Conductivity	39 mmho/cm	+0.0176
	31 mmho/cm	+0.0121
	21 mmho/cm	+0.0080

This data is incorporated in the CTDCAL program currently used during probe calibration and makes these corrections automatically.

The CTD was cleaned with the recommended .1 N HCl solution prior to being placed in the bath.

c) SALINOMETER DATA

The Beckman Salinometer was also set up to make salinity measurements of water samples from the bath. The salinometer was calibrated with Wormley water and then samples of the bath were taken for salinity measurements using the Neil Brown CTD and Beckman Salinometer. A summary of this is shown below:

	NB CTD	Beckman Salinometer	•
1st try	33.811	33.646	0.165
2nd try	32.309	32.351	0.042
3rd try	32.347	32.355	0.008

Before probe calibration the salinity was brought up to 38 +/- 1 ppt. Prior to each calibration, HI, MID and LOW, a water sample was taken for a salinity check with both instruments. Results of these samplings are shown below:

	NB CTD	Beckman Salinometer	•
High cal.	37.777	37.918	0.141
	37.814	37.933	0.119
Mid cal.	38.01	38.157	0.147
Low cal.	38.002	38.029	0.027

Since these measurements did not agree as closely as expected, water samples were taken immediately before and after each calibration using the soda lime bottles from the Woods Hole Oceanographic. These samples have not been submitted for analysis, but have been kept should there be a need to investigate the discrepancy between the Neil Brown and Beckman salinity measurements.

2. CALIBRATION READINGS, CALIBRATION CONSTANTS

For each probe at each temperature and conductivity, 50 data samples were taken of:

a) NB temperature
b) NB conductivity
c) XCTD thermistor resistance
d) XCTD conductivity cell resistance

As a measure of internal consistency of the three calibrations, for each sample taken the XCTD conductivity cell constant was computed as follows:

$$\text{XCTD cell constant} = \text{NB conductivity} \times \text{XCTD conductivity cell resistance}$$

The cell constant is a geometrical property of the cell and should remain constant if the cell dimensions are constant.

The average of the 50 samples was used to compute the calibration constants.

Typically the fifty data samples were obtained without trouble. However, due to the "spiking" problem (see Sec. IIID3) up to 30% of the data points were discarded and not included in the average used to compute the calibration constants.

A summary of the calibration constants and the cell constants for each probe deployed at sea is shown in of the Appendix.

3. NOTES, RECOMMENDATIONS

Overall the HI calibration was difficult because the probes did not want to turn on. The usual symptom was that all the frequencies were the same, about 250 Hz. After a considerable amount of shaking 9 out of 12 probes eventually turned on and calibrated at high temperature and conductivity.

Two of the three probes that could not be calibrated had all the frequencies below 410 Hz.This could mean that the probe never completely turned on or had some other internal electrical problem as a result of potting. The third probe was completely dead and did not have a "prepot tested" sticker on it. Presumably it did not work and somehow got mixed into the batch of good probes and potted.

In general the probe output, which was monitored on an oscilloscope, was "spiky", particularly on the HICAL, but on the other frequencies as well (see Section VIII for the results of some investigation into the cause of this). The normal probe output is a frequency burst followed by a quiet time at the op amp rail. This spiking behavior would often occur close to the end of the HICAL frequency and consist of the output jumping to and being pinned at the opposite rail until the normal end of the frequency burst, followed by a normal quiet time at the usual rail.

The spiking behavior seemed to get worse with each successive calibration. For the MID calibration one probe had so many drop outs the average had to be computed by hand. For the LOW calibration, two probes were done by hand.

After the final LOW calibration the probes were rinsed in fresh water and placed in an oven for 4 hours to dry out. During the fresh water rinse one probe produced a loud crack - like glass cracking. This probe subsequently worked at see without a problem. The attempt to dry the probes was completely unsuccessful since water was observed to drip out of them when they were being packaged for shipping.

IV. AT-SEA TEST PROCEDURE & RESULTS

A. TEST SET-UP

A sketch of the test set-up is shown in the Appendix. The equipment was set up on board the R/V Weatherbird the day before going to sea and overall operation of the system was checked using an XCTD simulator.

B. LAUNCH SEQUENCE & PROCEDURE

The probes were launched in order of increasing expected reliability according to observations made during the calibration procedure. For each sea test the launch order was as follows:

September	November
Probe 6	Probe 20
" 7	" 13
" 8	" 14
" 10	" 15
" 11	" 16
" 1	" 17
" 3	" 18
" 5	

It should be noted that the at-sea weather conditions for September were flat calm and for November were 8-10' swells, 4' seas and 20 mph winds.

For the September test, Rich rinsed all units with soapy water through the conductivity cell and bucket tested them before launching.

For the November test, we chose not to soap the probes and Bruce bucket tested the first four units. These four units remained partially to completely turned on for the time between the bucket test and launch. This was probably a source of confusion for the deck gear in determining the start of signal and start of descent. The last three probes were therefor not bucket tested.

For both sea tests the data was recorded from the ANALOG OUT port of the deckgear to cassette (see section VIA).

C. AT-SEA RESULTS

1. SEPTEMBER SEA TEST

Probe 6 tested OK in the bucket but gave no signal after launch.

The next four probes, 7,8,10 & 11, bucket tested well and gave signals after launch that looked good on the oscilloscope with the exception of the expected HICAL dropouts. This data did not transfer to the computer and there was no storage of digital data.

The last three probes, 1,3 & 5, gave good signals, generated computer graphs and stored as digital data.

2. NOVEMBER SEA TEST

Probe 20 gave no signal during the bucket test. Checking with a voltmeter showed that the probe output was sitting at the rails.

Probe 13 when bucket tested showed a novel mixing of the probe frequencies. The signal looked like the control signal for the sample and hold was shifted to sample across two frequencies rather than within one frequency. This probe was launched anyway and recorded. It did not produce any graphics or digitized data.

Both probes 14 and 15 bucket tested with the usual number of HICAL dropouts (as experienced during calibration). They gave reasonable looking signals on the oscilloscope after launch. The deckgear did not start at launch but was restarted at a later point in the drop when most of the HICAL dropouts had gone away. Starting at this later point the computer was able to generate graphic and digital data for these two probes.

At this point in the test the deckgear developed transfer problems and the MK9RV3 program would not step past the checking of the board code section. The remaining three probes, 16,17 & 18, were launched and recorded on tape only.

V. POST-TEST DATA PROCESSING

A. TAPE PLAYBACK

1. SEPTEMBER SEA TEST

Two tape recordings were made of the September sea test data. Of these two, the recording from Tape Deck #1 was deemed no good due to a tape speed error, and the recording from Tape Deck #2 was used for all the tape playbacks.

The initial playback attempts showed that the deckgear had all the same problems it had at sea. This was determined to be a result of not being able to reliably latch onto a LOCAL frequency. A prototype deckgear was breadboarded together that ignored the value of the frequency and just measured a frequency if one was present (see IIB2). Tape playbacks into this deckgear allowed us to process the data, though it was noisy. A redesign of the prototype allowed for the recovery of the September sea data to within the attainable accuracy that is currently available from a direct tape recording. This data was subsequently uploaded to the VAX and processed as described below.

2. NOVEMBER SEA TEST

The tape recording made of the November sea test suffered from not having the Automatic Recording Level of the tape recorder turned off. This kind of problem is unique among Sippican probes to the XCTD since the time multiplexing of the XCTD signal makes analog recording of it difficult. This tape was useless and playback of the November data was not possible.

As a result of this mistake the at sea test set-up has been modified to look at the XCTD probe signal with the oscilloscope at the output (read head) of the tape recorder.

B. TRANSFER PROCEDURE TO VAX

Data that was MK9 processed and stored on disk at sea was uploaded to the VAX through HP supplied software.

Data that was recorded in its analog form and processed back at Sippican was uploaded in a slightly different manner. Uploading from the HP is a time consuming procedure. Approximately forty minutes per file are required to load the data from disk to tape and subsequent uploading to the VAX. To try and reduce this time, the data was transfered directly from the disk on which is was stored to a personal computer, a Multitech 900. There are two steps to the upload procedure.

Step 1 of the transfer of the data from the HP micro-flexible disk requires the use of two programs:

"D_TO_PC" on the HP85
"XCTD.BAS" on the Multitech 900

These two programs working simultaneously transfer the data via an IEEE bus to the Multitech. The Multitech writes the data to its hard disk.

Step 2 requires that the Multitech be configured as a DECNET node (see John Botelho). Then one can invoke the Network File Transfer Utility and copy the data file directly onto the VAX.

This procedure reduced the time for uploading data files to approximately 8 minutes.

C. VAX PROCESSING PROCEDURE

Several forms of processing were applied to the data and several programs were developed by Bruce to compute and plot the results. These programs are:

DATA_SORT
FILTER
DATA_CRUNCH
PLOT

These programs are all located in the subdirectory SOSIDATA.XCTD. They can be run directly and are basically user friendly, requiring some interaction, particularly for input and output files.

1. FREQUENCY VS. DEPTH PROCESSING

Due to the presence of invalid data, the conventional reduction process was incorrectly calculating elapsed time. The data reduction scheme was therefor modified to be more fault tolerant of data dropouts and obviously erroneous data. The program DATA_SORT reads the data file containing the raw numbers obtained by the deck gear and converts this number back into a frequency. It then determines if the frequency obtained is a valid LOCAL signal. If it is, then the program assigns the next three data bytes as COND, HICAL and TEMP. If it is not a valid LOCAL, the program determines if it is a valid HICAL signal. If it is, then the previous two samples are assigned LOCAL and COND respectively and the next acquired sample as TEMP. Every data byte counts as 62.5msec when computing elapsed time and subsequently depth. The output of the program DATA_SORT is a file with 5 columns of numbers, i.e. depth and the four frequencies ordered as follows:

DEPTH LOCAL COND HICAL TEMP

If neither the first number is LOCAL or the third number is HICAL, the program increments its index by one and the test is repeated on the next four numbers.

2. TEMPERATURE AND CONDUCTIVITY DATA PROCESSING

Once the frequencies have been recovered, the program DATA_CRUNCH is used to compute temperature, conductivity and salinity (Ref. UNESCO 44, 1983, Algorithms for computation of fundamental properties of seawater). Any or all of these parameters can be requested. These calculations are made using the algorithms documented in MK9 SOFTWARE REVISION REQUIREMENTS FOR INTEGRATION OF XCTD PROCESSOR, R-1414, and the calibration constants associated with each probe. This program requires a file made by DATA_SORT and makes a file with a user specified name with the depth and requested parameters.

DATA_CRUNCH also eliminates outlying points by calculating for each point the RMS value of the surrounding 50 data points and removing those more than three standard deviations from the mean. Those points removed are substituted with the recalculated average minus the outlying point.

The program FILTER is used optionally to smooth the data and does so using an equally weighted sum of points divided by the number of points moving average. The window length is entered interactively. This program requests an input file from the user and generates a new file with the same format as the input file and a user specified name.

3. PLOTTING PROCEDURE

The program PLOT is a general, interactive plotting program which can handle up to 4 variables. This is the program used to plot any of the data generated by the previously mentioned programs.

VI. RESULTS

This section is a guide through the 35 graphs that fill up the rest of this report.

The results of the September test data stored at sea, probes 1,3 & 5, are shown in Figs. 1-6. Figs. 1-3 are the probe frequencies vs depth and Figs. 4-6 are the temperature and conductivity vs depth.

The next series of graphs, Figs. 7-13 show frequency vs depth for the tape playbacks of all the probes deployed in the September sea test. These graphs were made using the latest redesign of the deckgear. Most of the spikes on these plots are transpositions of data rather than errors in calculating the frequency. The plot for probe 11 is short because the tape ran out.

Figs. 14-20 show the temperature and conductivity vs depth for all the probes deployed in the September sea test. The noise present on these plots matches closely the noise obtained from a test playback that was done to determine the best accuracy obtainable from the current tape record/playback configuration.

The temperature and conductivity data shown in Figs. 14-20 was smoothed with a 50 point moving average on HICAL and LOCAL, and a 6 point moving average on TEMP and COND. The result of this is plotted in Figs. 21-27.

The last 8 plots are the results of the November test data stored at sea for probes 14 & 15 and the intercomparison with the Seabird CTD. CTD cast #5 was used since it was the closest full length (1000m) cast to both XCTDs.

Figs. 28 and 29 show the frequency vs depth for probes 14 and 15.

Figs. 30-35 are the XCTD and CTD intercomparison. Since each XCTD started sending data at some deep depth, the depth scales of the XCTD and CTD had to be adjusted for the best alignment. Therefor each XCTD uses a different section of the CTD data for intercomparison purposes.

Figs. 30 and 31 show the intercomparison of temperature and conductivity for XCTD probe 14. Figs. 32 and 33 show the intercomparison of temperature and conductivity for XCTD probe 15. Figs. 34 and 35 show the intercomparison of salinity for XCTD probe 15.

VII. ANALYSIS OF TEST RESULTS

Comparison of September and November digital data (frequency plots) for the two different deck gears shows that the redesigned deck gear does a better job with real time data.

Intercomparison of the reprocessed September profiles shows good repeatability - all temperature traces overlay and all but one conductivity trace (#1 which is +3mmho/cm off) overlay.

Assuming the necessary depth offsets made are correct, the comparison of the November XCTD profiles with the CTD show good agreement, and the two salinity profiles show agreement to within the allowed tolerance of .05 ppt.

VIII. SUBSEQUENT DEVELOPMENTS

A record/playback experiment of the XCTD signal was done to determine the accuracy of a tape playback done under ideal lab circumstances. It was found that taping of the signal as we have been doing does not allow the signal to be recovered via playback with the necessary accuracy of +/- 0.03.

The HICAL dropout problem has been shown to be a function of the BT wire getting wet. This problem develops a few seconds after the probe spool gets wet and persists until the probe spool is completely wet. The varying capacitance between the BT wire and the water that developes as the spool gets wet causes the line driver to become unbalanced. When the BT wire is either totally dry or totally wet this is not a problem.

Table 1. Summary of probe calibration numbers.

Probe Serial #	Temperature			Conductivity		
	2nd Term	1st Term	Constant	2nd Term	1st Term	Constant
1	1.6446e-7	2.7873e-4	1.1714e-3	-3.681e+6	4.8459e+4	-2.093501
3	2.5641e-8	3.1610e-4	9.3762e-4	-2.321e+5	4.3063e+4	-9.453e-2
5	3.1632e-6	-2.436e-4	3.8135e-3	-5.617e+6	5.5987e+4	-9.091452
7	5.1597e-7	2.1648e-4	1.4912e-3	-4.488e+6	5.0732e+4	-3.151511
8	2.0210e-7	2.8192e-4	1.1186e-3	-1.918e+6	4.4614e+4	-1.745951
10	8.9744e-8	2.9999e-4	1.0386e-3	1.3761e+5	4.2832e+4	0.1329806
11	3.3463e-7	2.3169e-4	1.4678e-3	-6.277e+6	4.8008e+4	-1.465531
13	-5.650e-7	4.3283e-4	3.1118e-4	3.6157e+5	4.3328e+4	0.2133030
14	6.1210e-7	1.8303e-4	1.7165e-3	2.9795e+6	3.1993e+4	5.8022306
15	9.0680e-8	2.9923e-4	1.0701e-3	4.3620e+5	4.4173e+4	0.2851405
16	4.6504e-7	2.2265e-4	1.4678e-3	-1.960e+6	4.5098e+4	0.7492785
17	-5.922e-7	4.3406e-4	3.1285e-4	2.7406e+5	4.0502e+4	0.2802433
18	-4.550e-7	4.0770e-4	4.5371e-4	6.4578e+5	4.1155e+4	0.7033724
19	-2.440e-8	3.1650e-4	9.6295e-4	-5.091e+6	5.2898e+4	-2.030524
20	1.5351e-6	4.2740e-5	2.3579e-3	-2.975e+6	4.8960e+4	-3.675646

Table 2. Summary of probe cell constants.

Probe Serial #	Cell constant High	Mid	Low
1	41.56	42.54	42.93
3	42.68	42.74	42.78
5	41.54	41.59	40.00
6	43.34	43.47	43.64
7	42.02	42.99	43.16
8	40.57	40.92	40.89
9	41.08	-	-
10	43.14	43.12	43.13
11	36.40	39.41	41.30
13	44.01	43.93	37.36
14	40.37	40.48	42.11
15	45.00	44.93	44.91
16	41.60	42.27	42.66
17	41.12	41.08	41.10
18	42.60	42.55	42.61
19	44.29	45.72	46.48
20	42.08	42.36	42.11

From nominal geometrical considerations, calculation of the cell constant = 42.78.

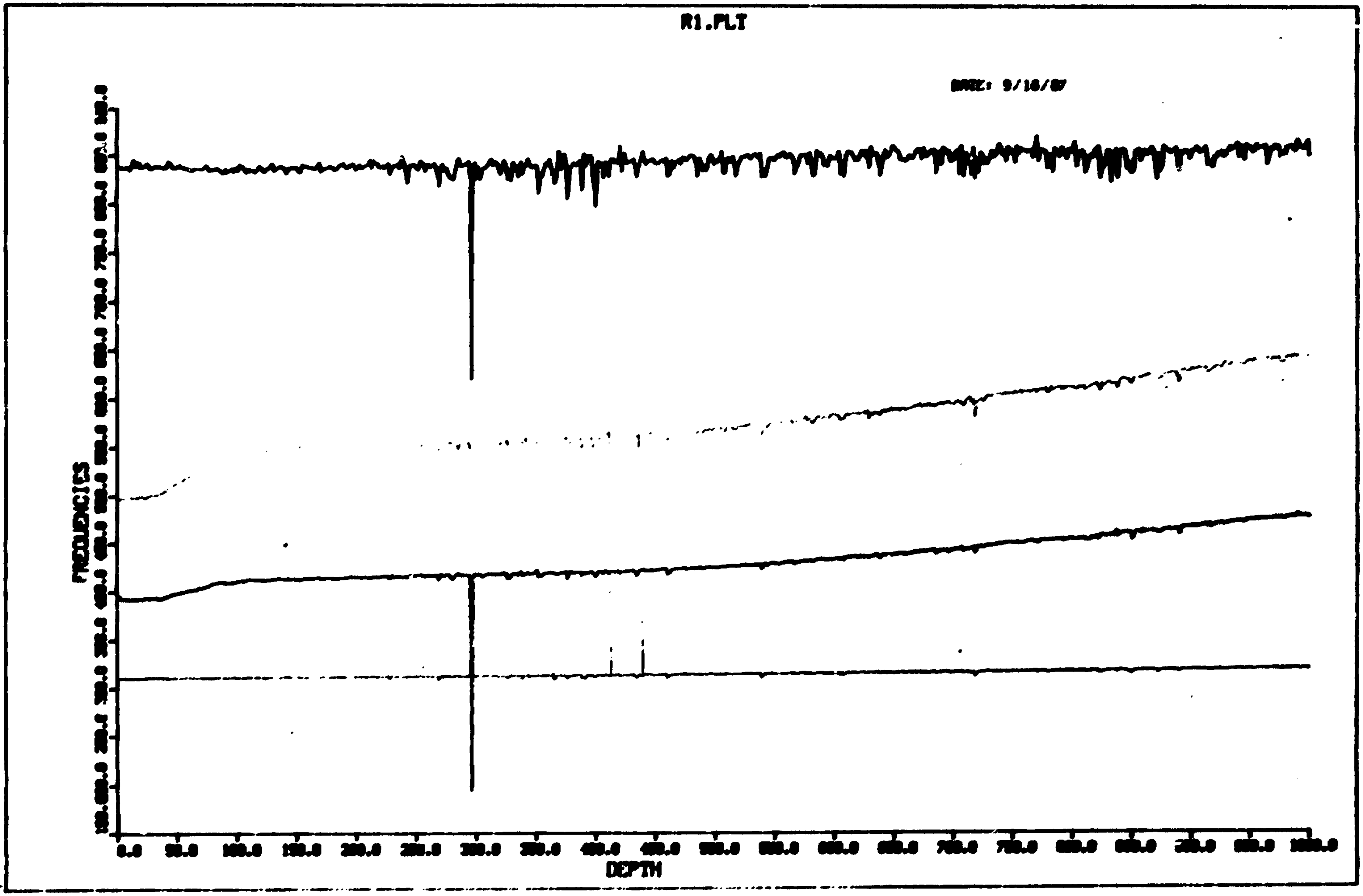


Fig. 1

Fig 2

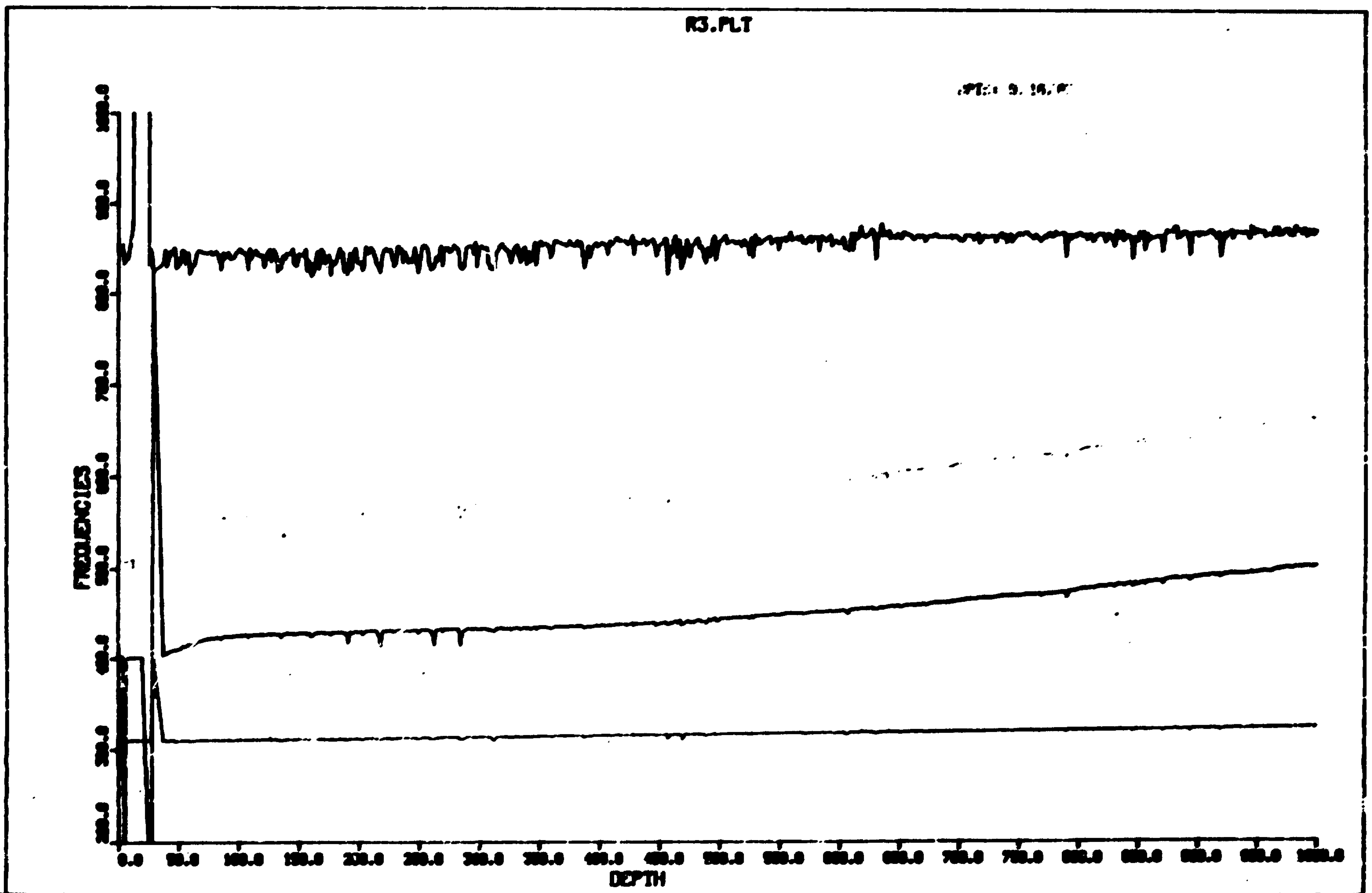


Fig.

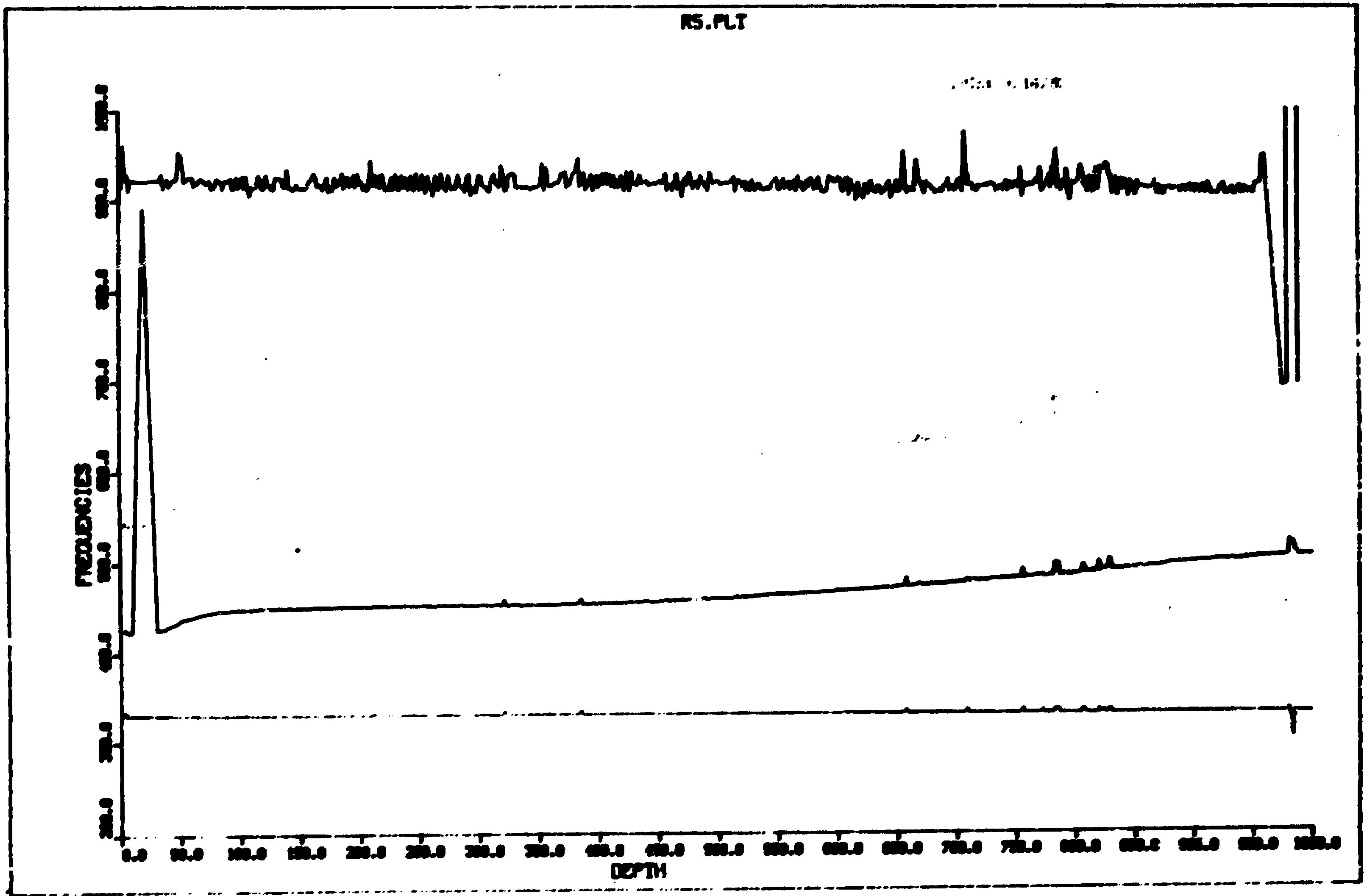
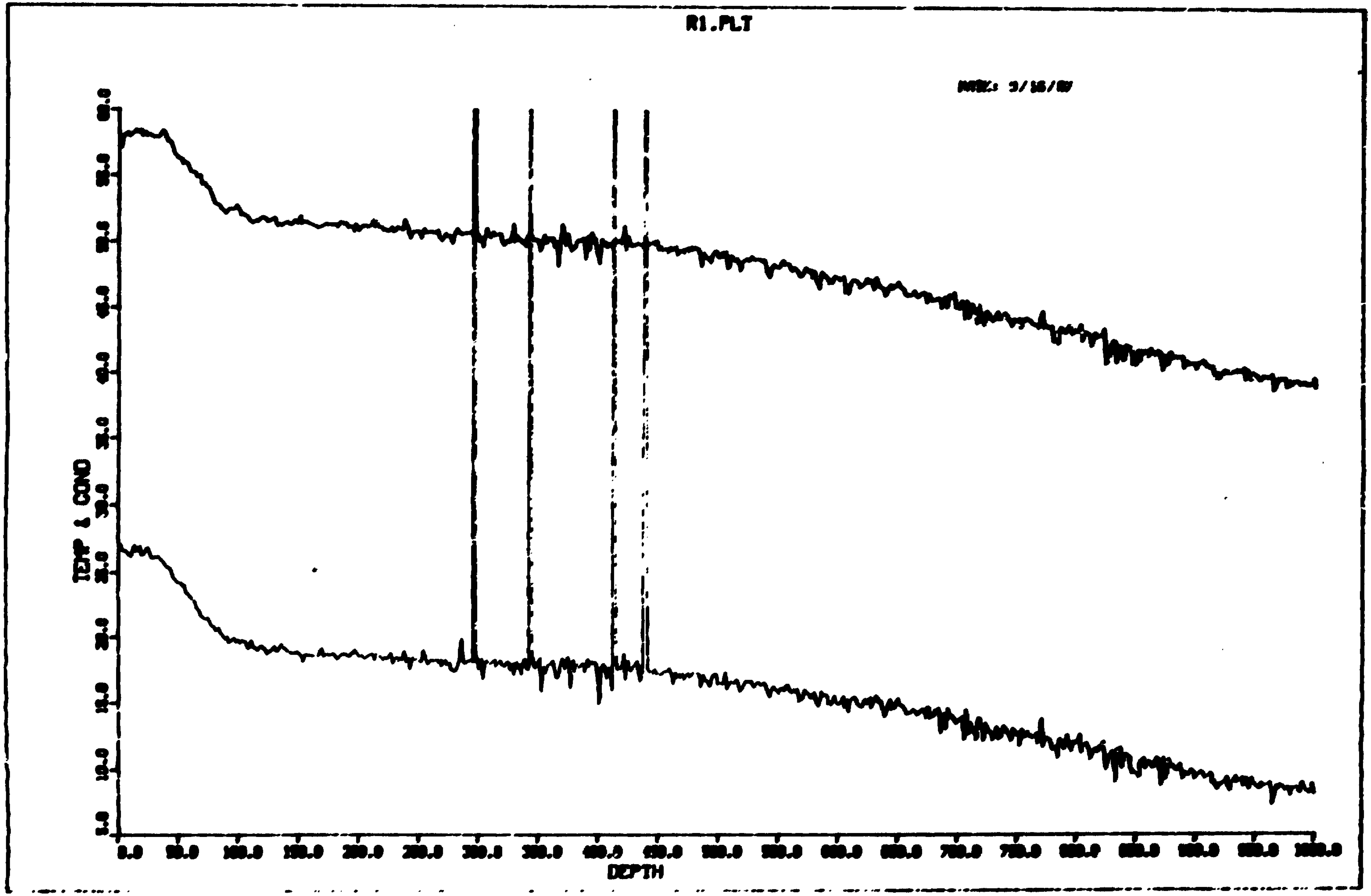
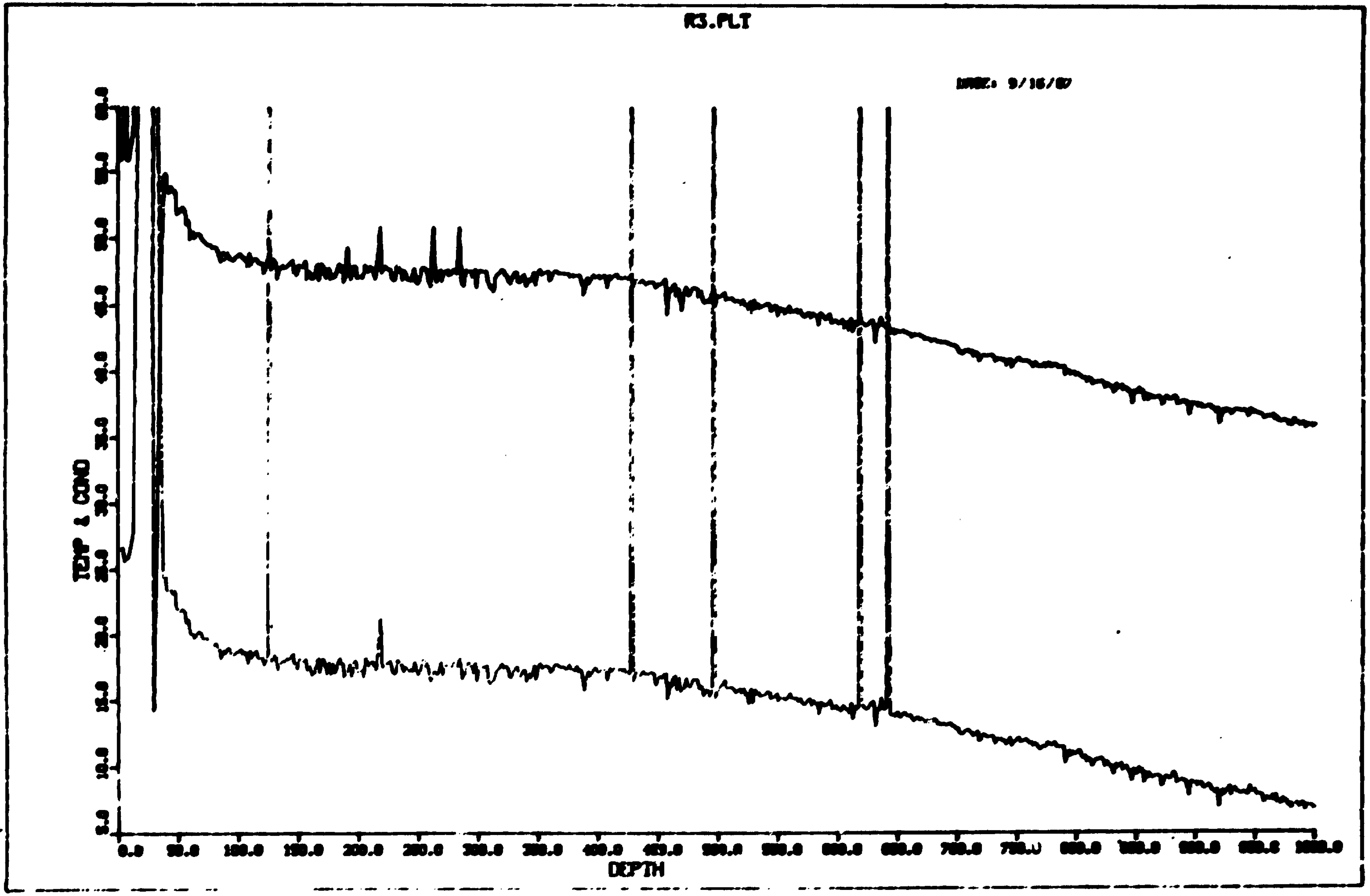
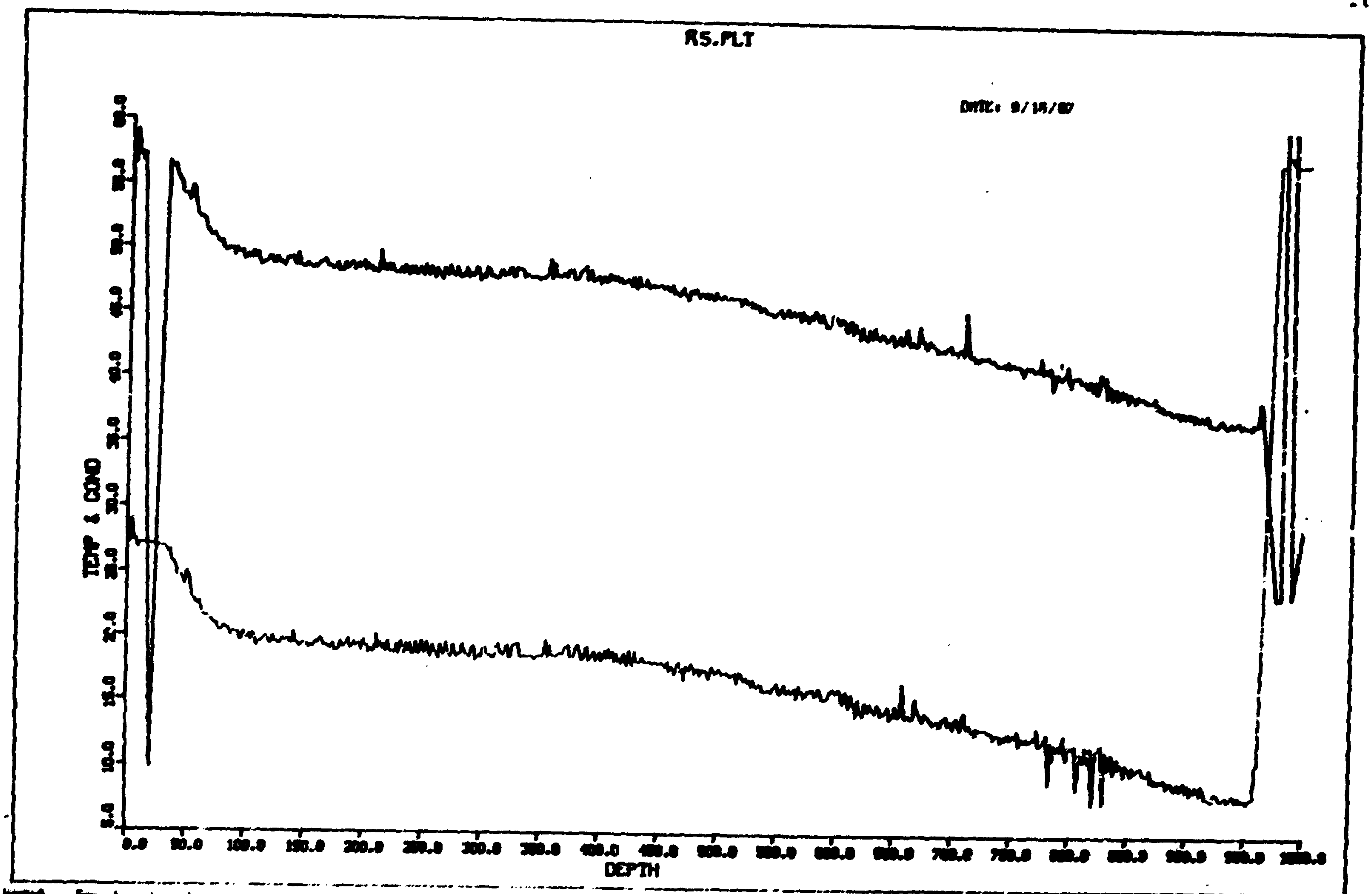
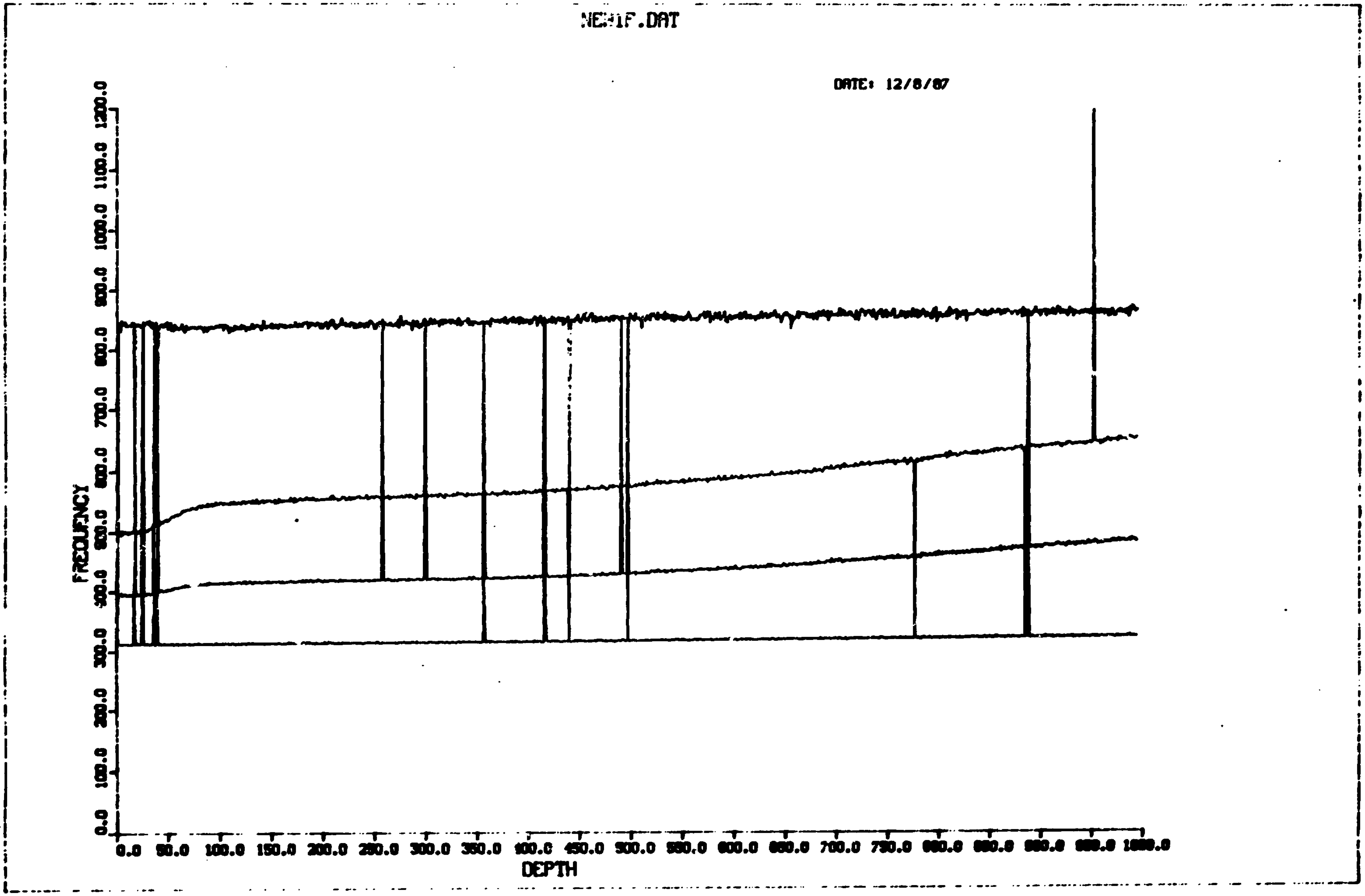


Fig.




R3.PLT
TEMP & COND
DEPTH


R5.PLT
TEMP & COND
DEPTH



NEW1F.DAT
DATE: 12/8/87
FREQUENCY
DEPTH
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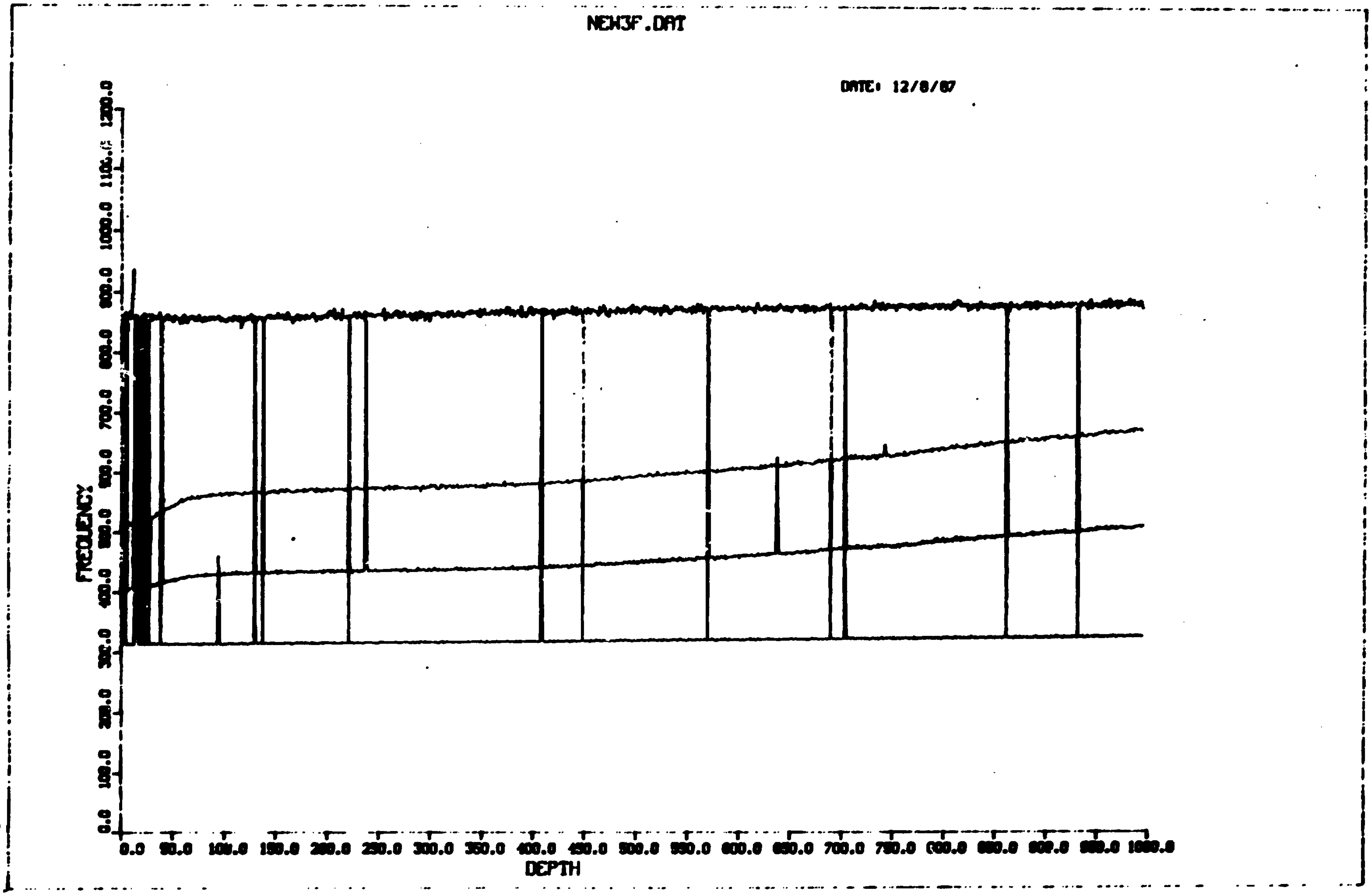
100.0
150.0
200.0
250.0
300.0
350.0
400.0
450.0
500.0
550.0
600.0
650.0
700.0
750.0
800.0
850.0
900.0
950.0
1000.0
1100.0
1200.0

Fig. 2



NEW3F.DAT
DATE: 12/8/87
FREQUENCY
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100.0
200.0
300.0
400.0
500.0
600.0
700.0
800.0
900.0
1000.0
1100.0
1200.0
DEPTH
0.0
50.0
100.0
150.0
200.0
250.0
300.0
350.0
400.0
450.0
500.0
550.0
600.0
650.0
700.0
750.0
800.0
850.0
900.0
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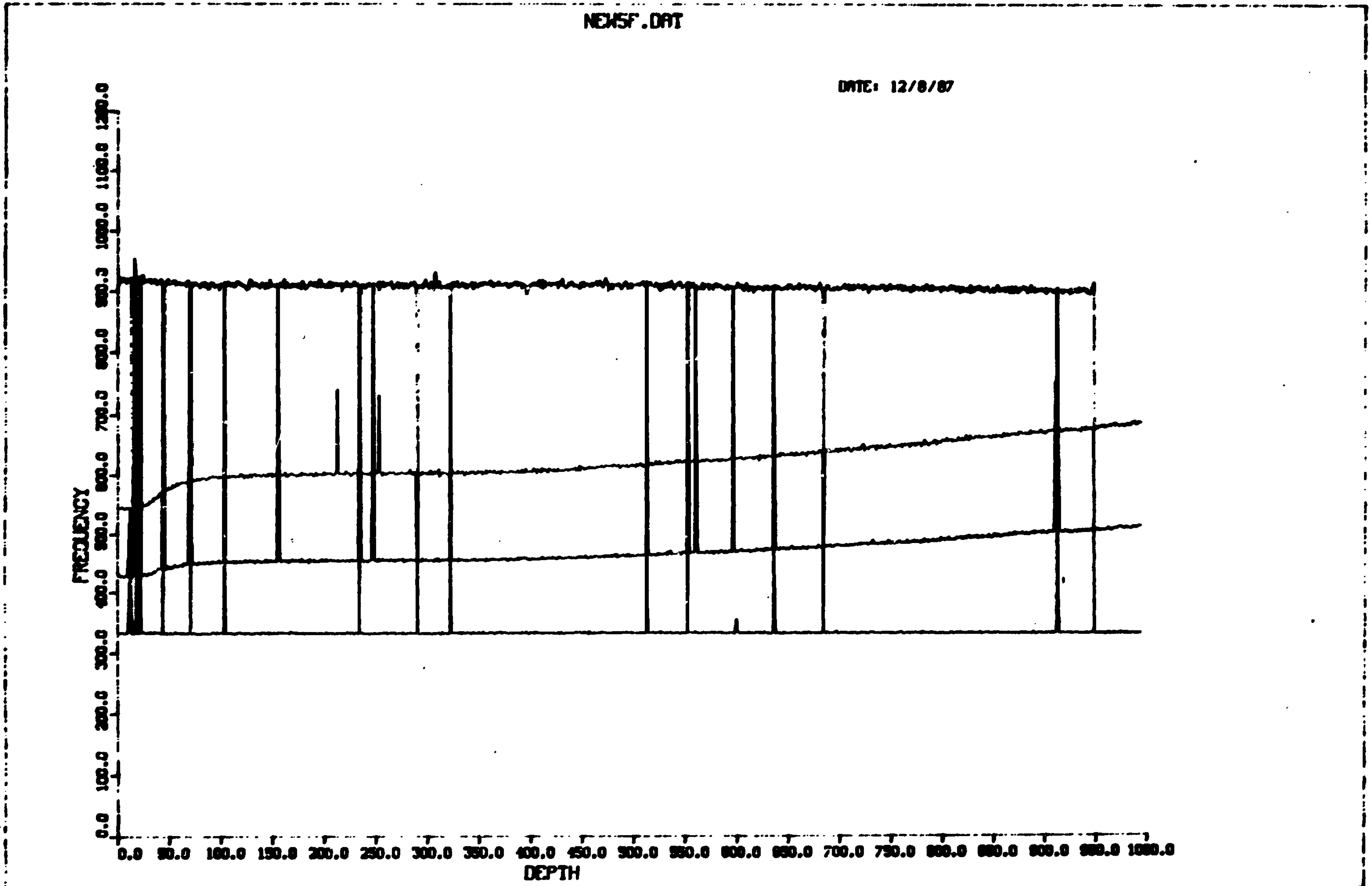

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Fig. 1C

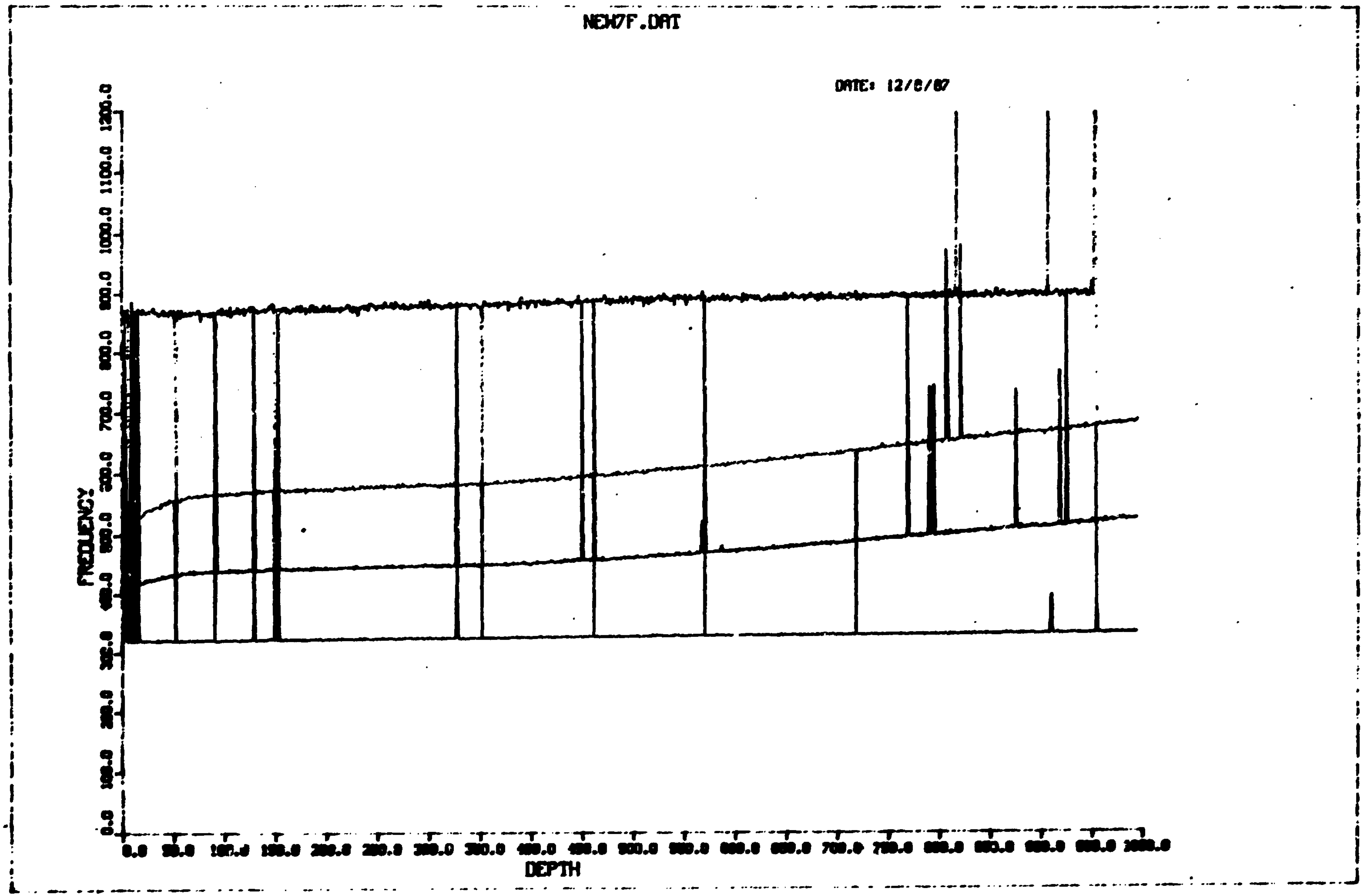

Fig. 11

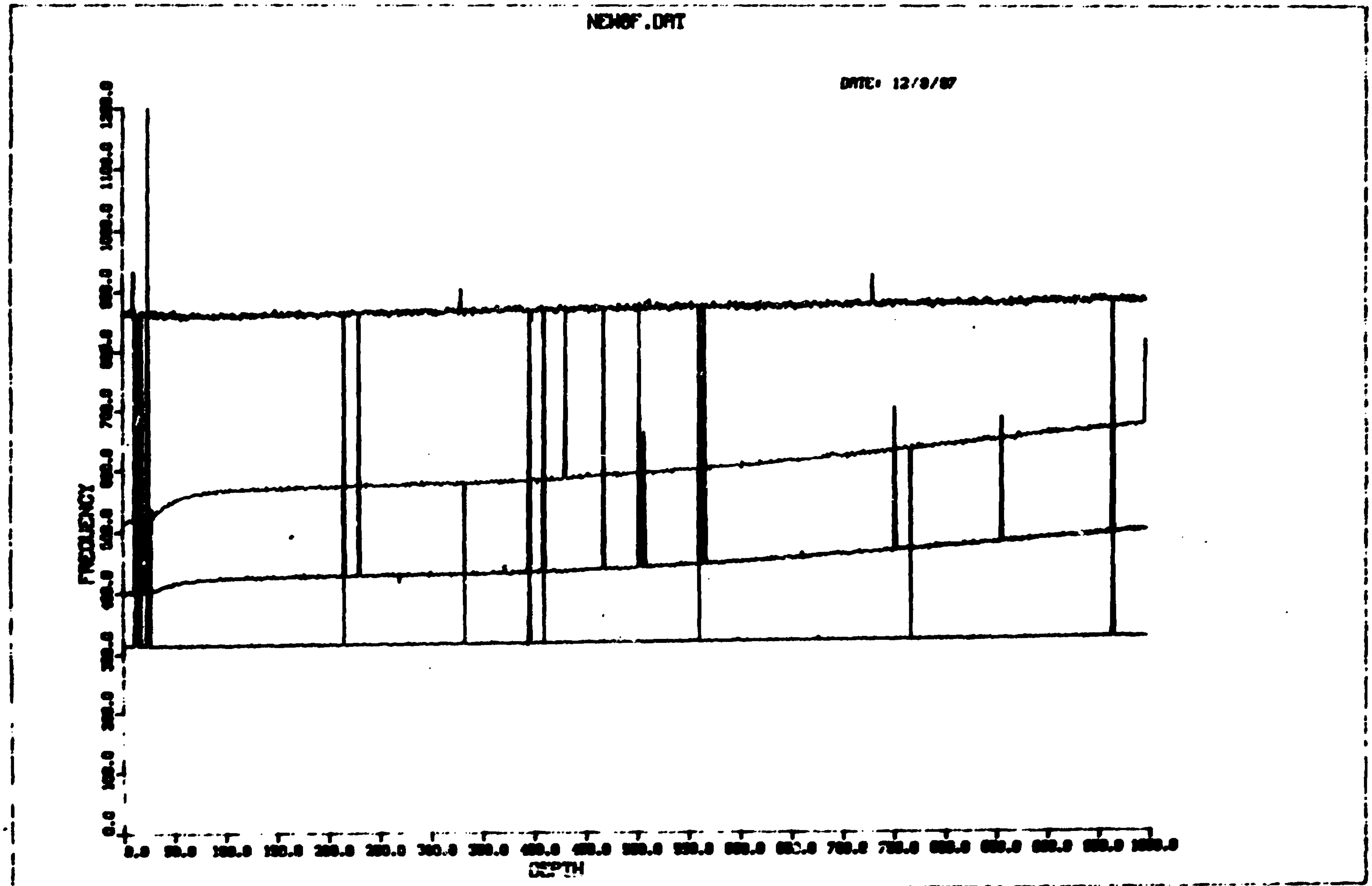
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Fig. 12

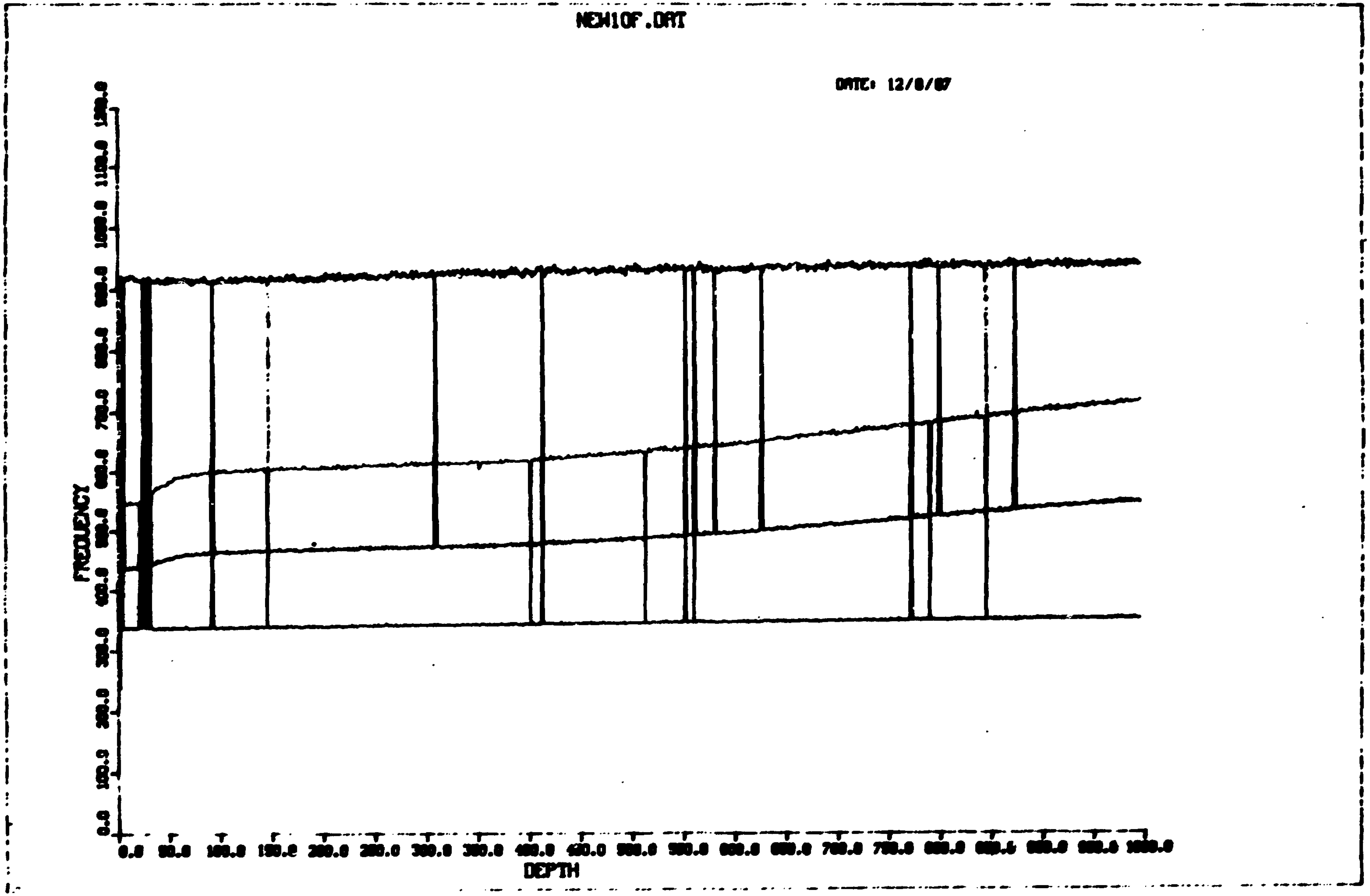


Fig. 13

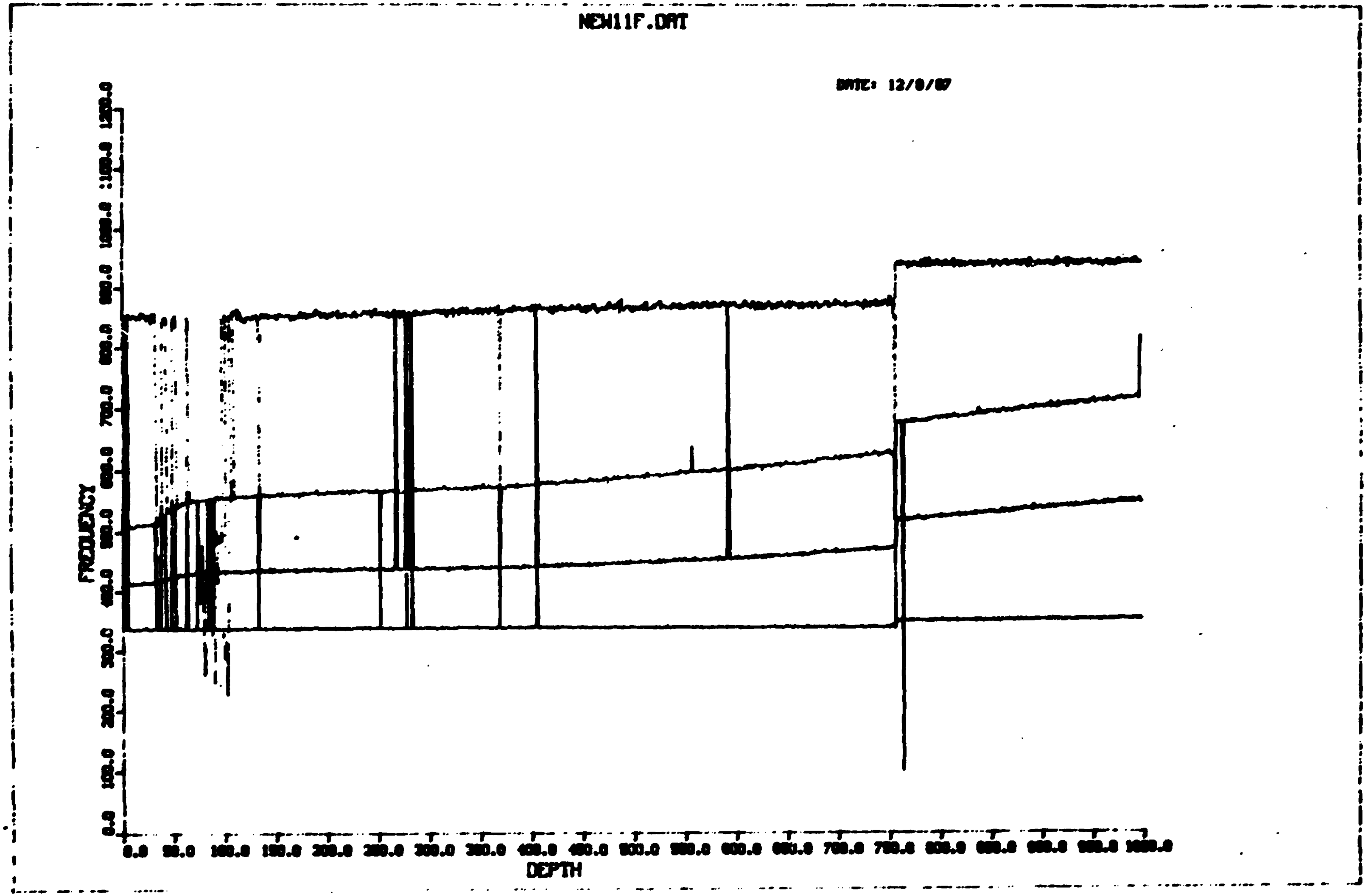


Fig. 14

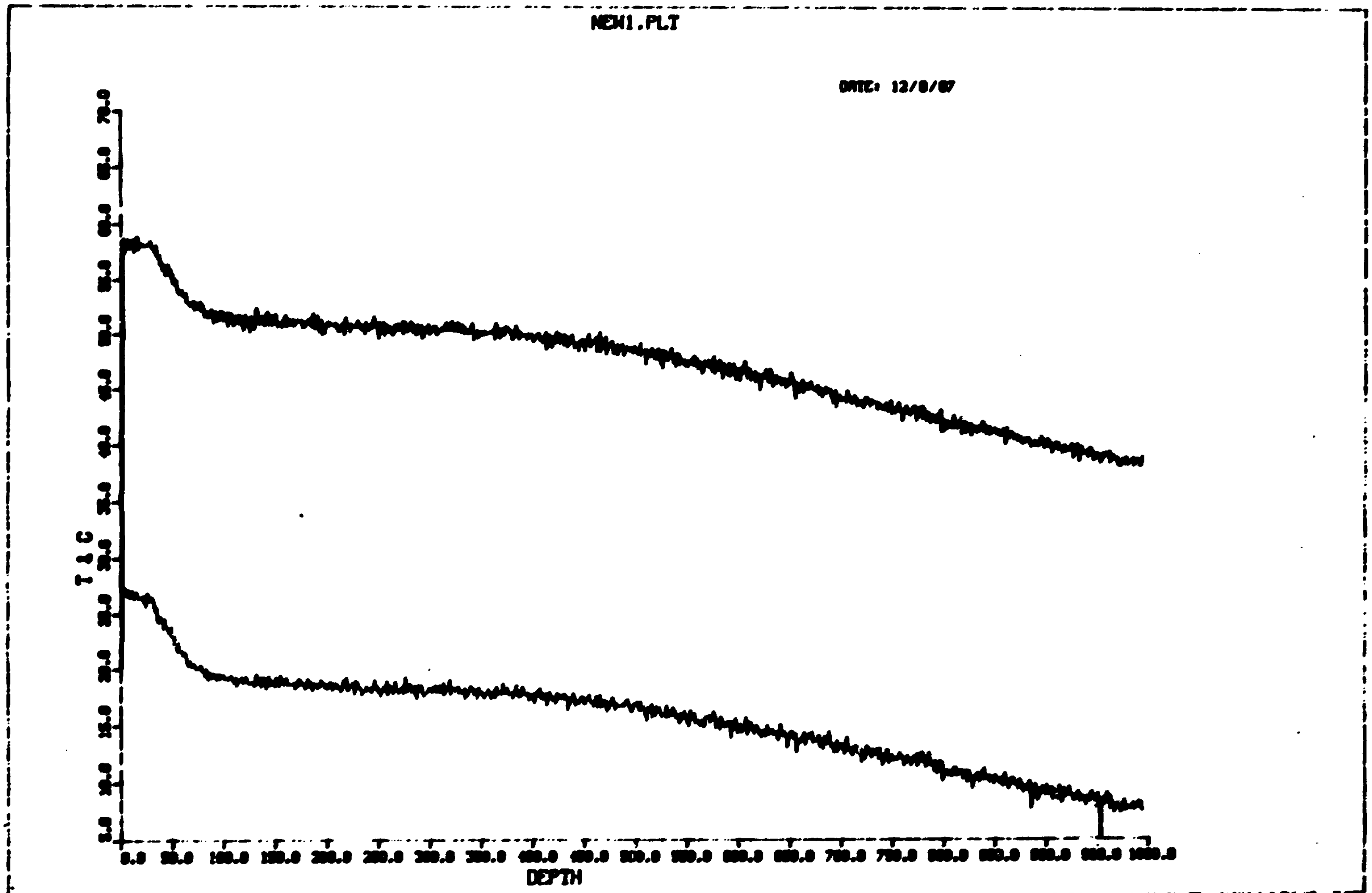
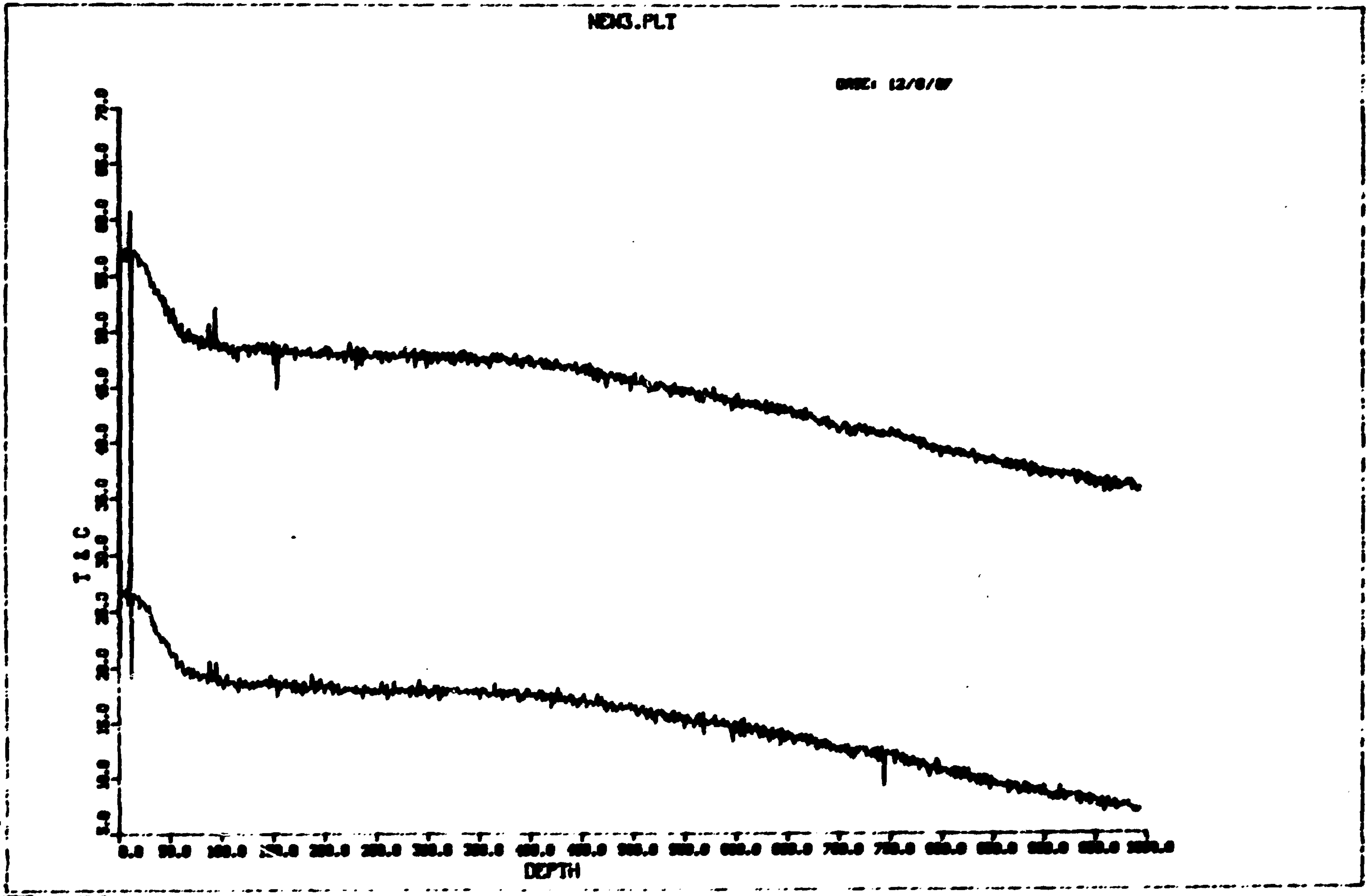
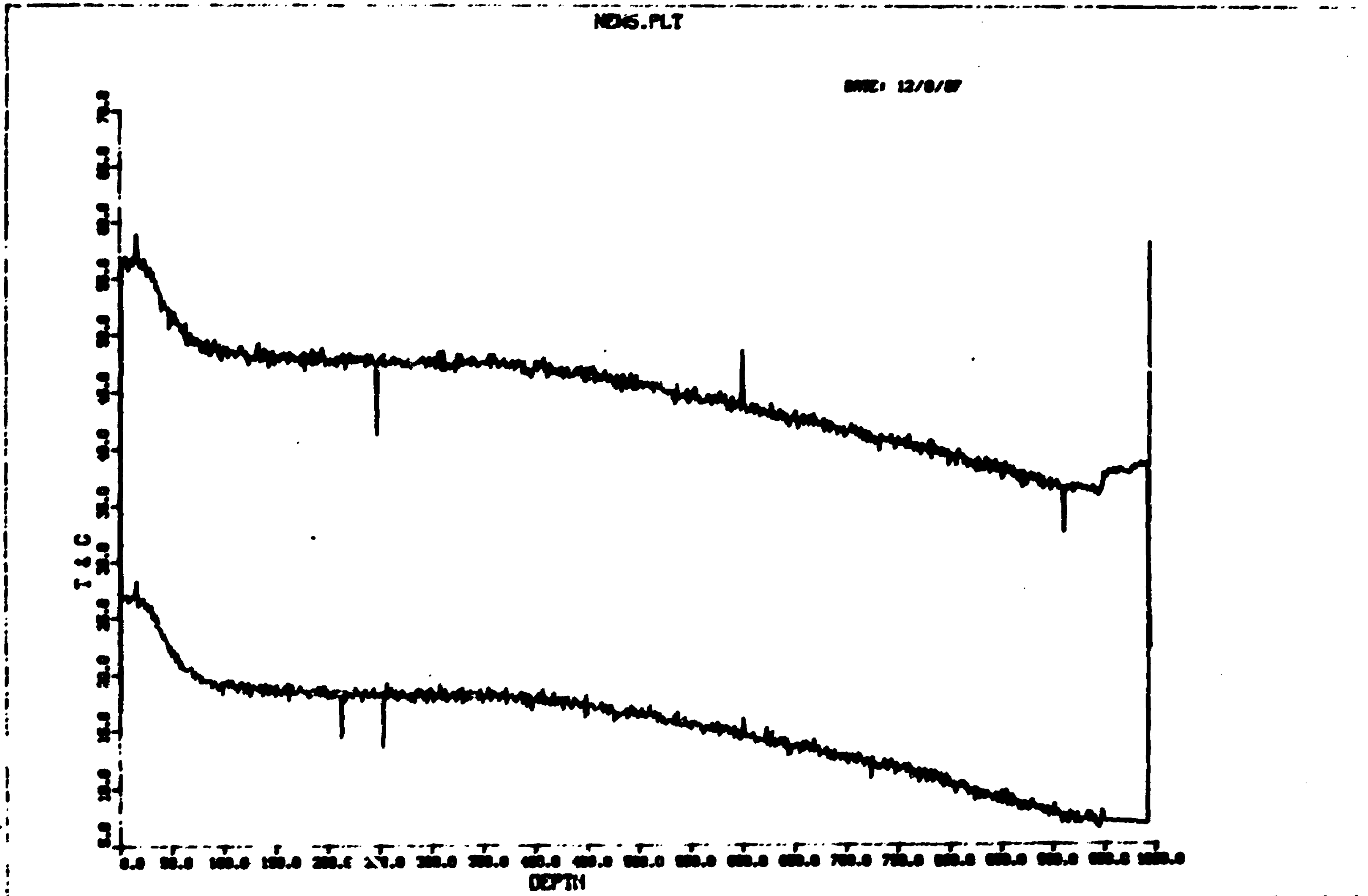


Fig. 15

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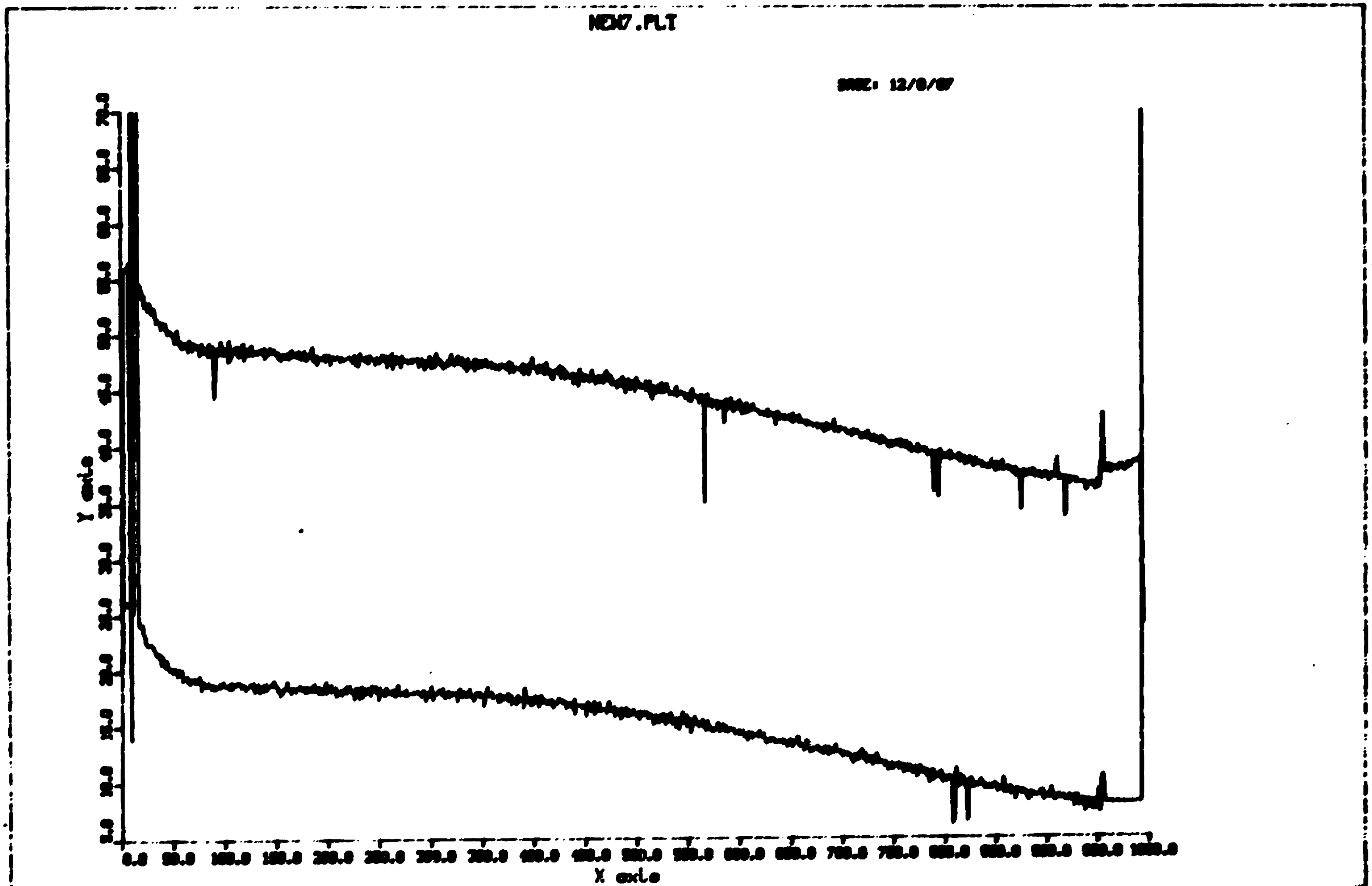
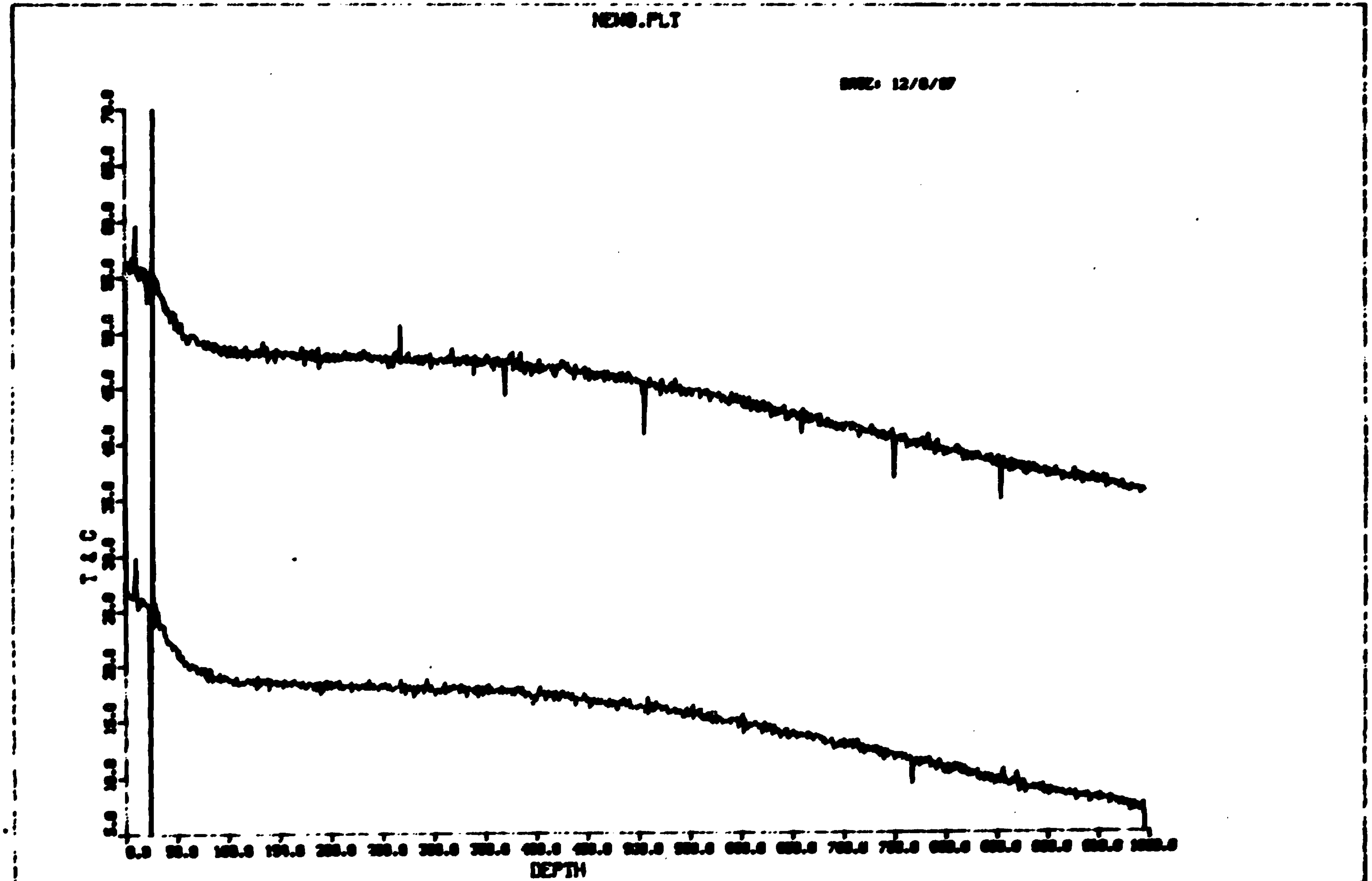


Fig. 17



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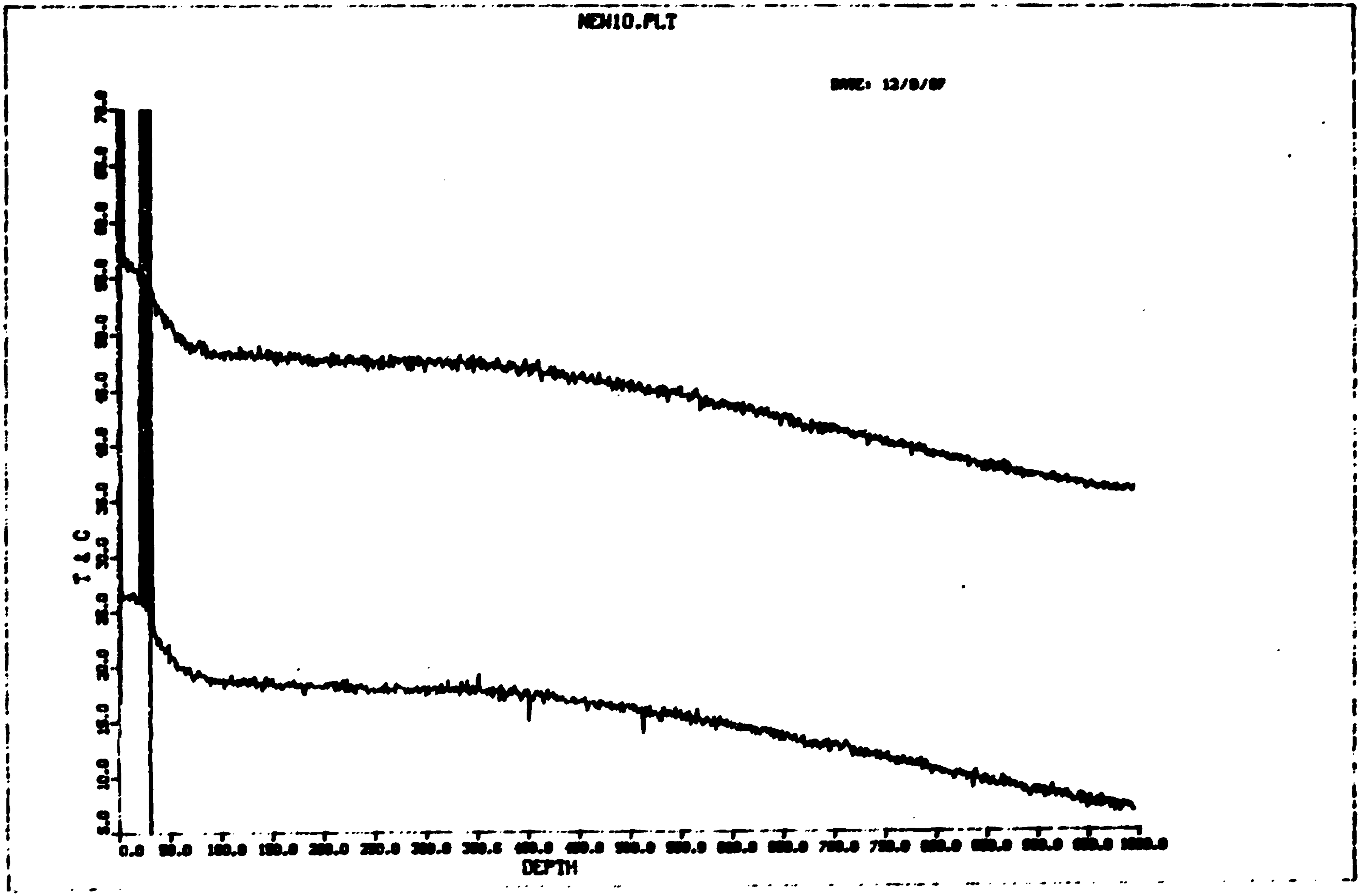

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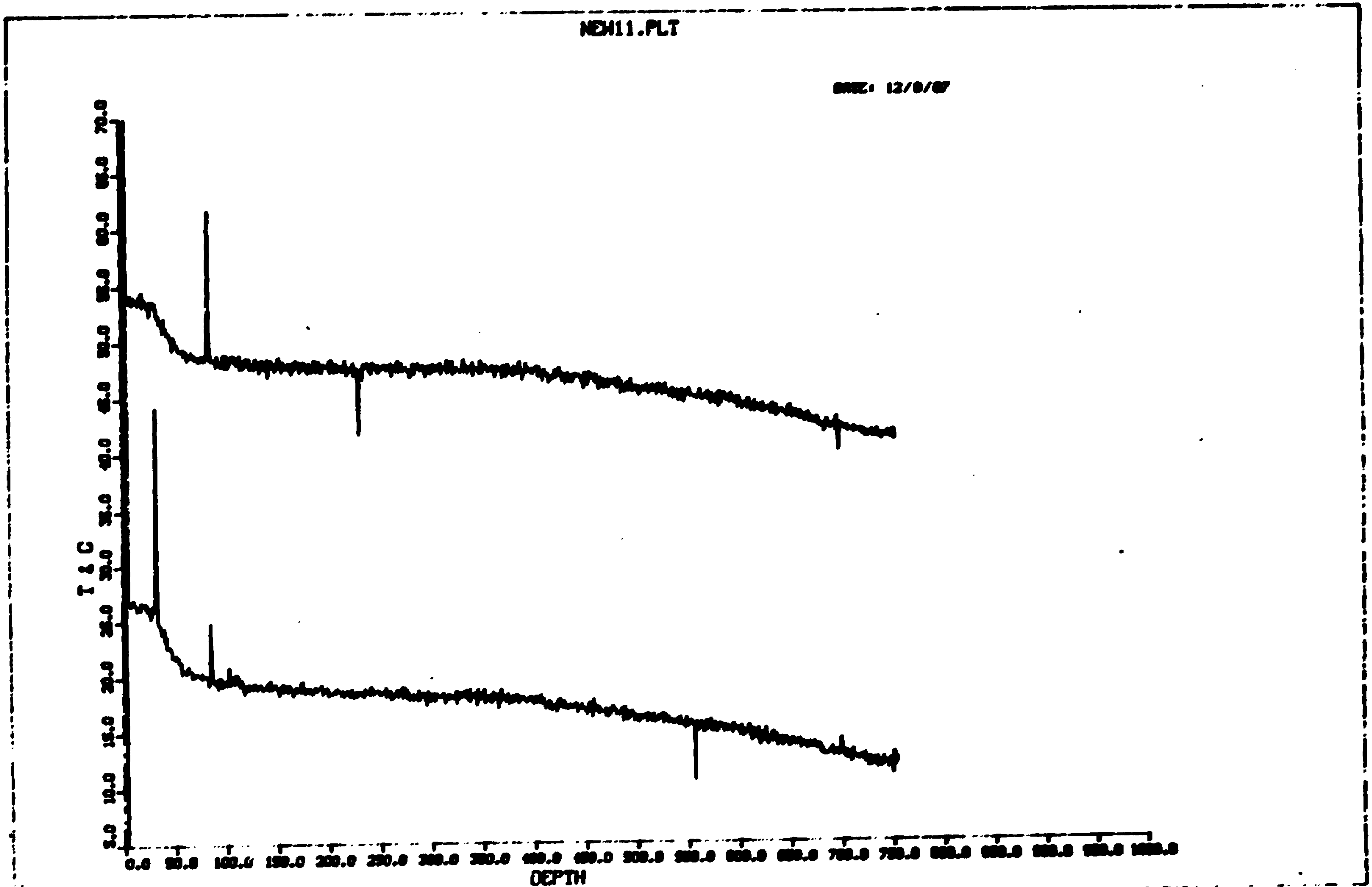
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12/8/87
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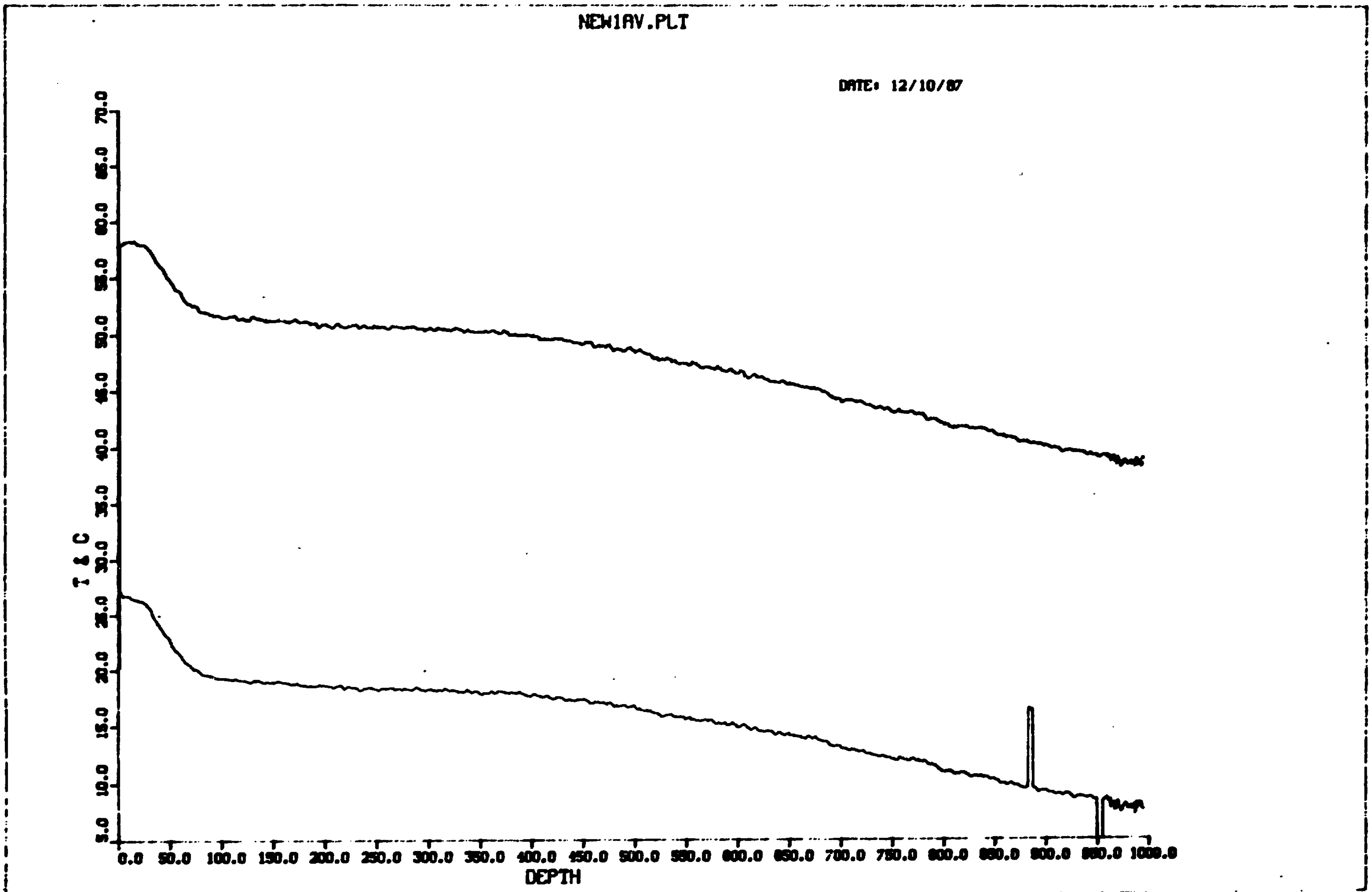
Fig. 8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DEPTH

Fig. 22

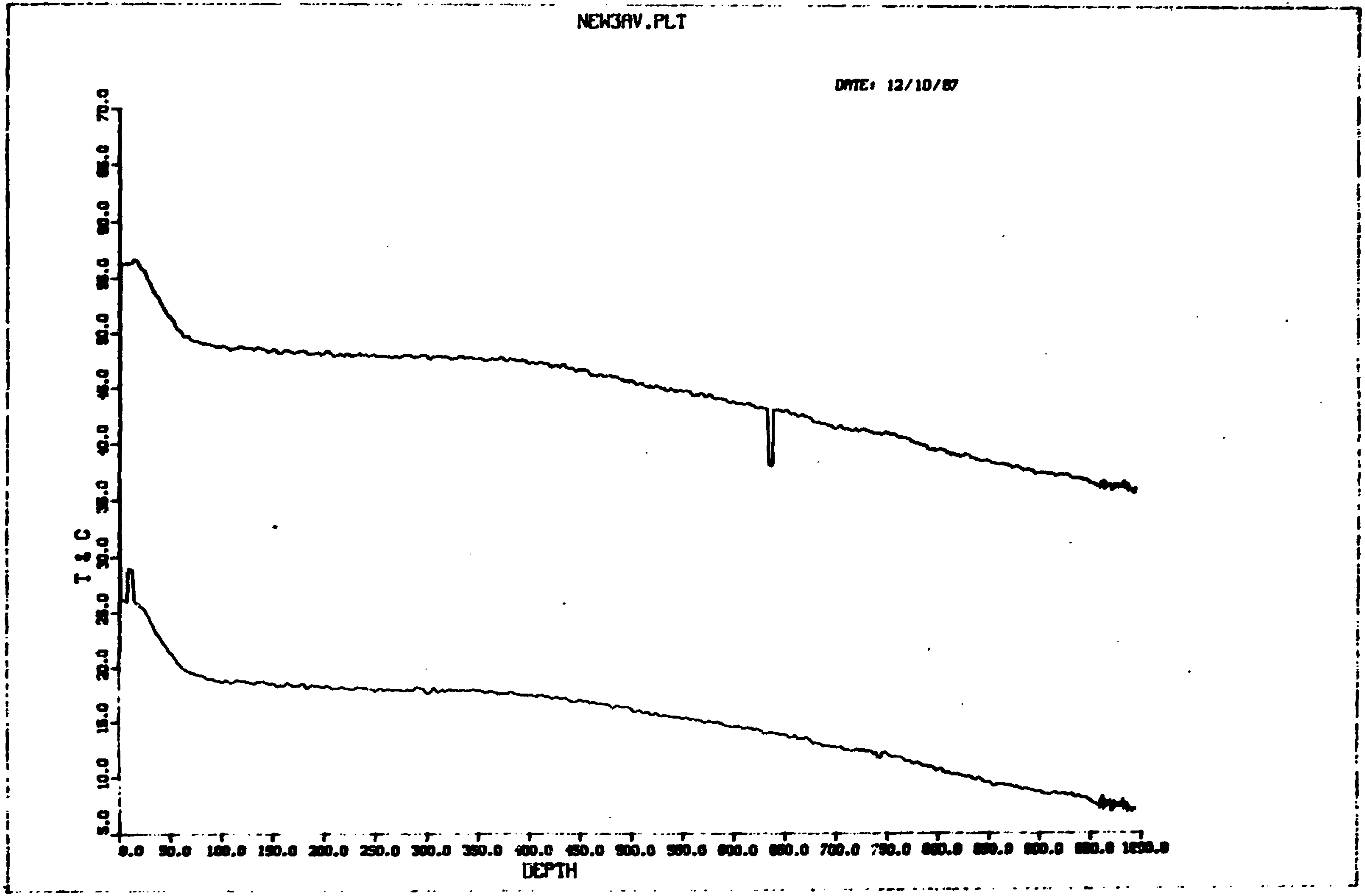
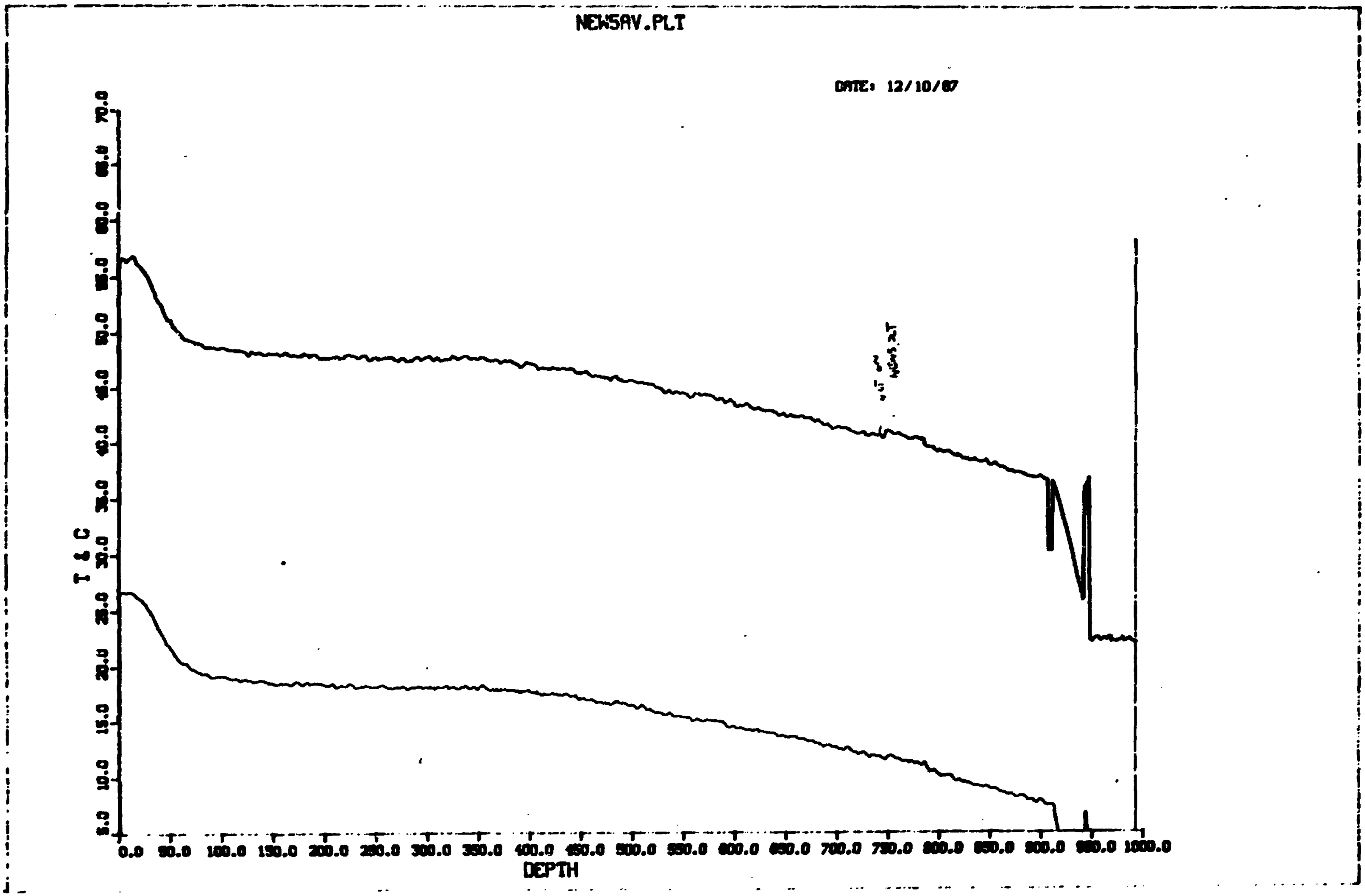


Fig. 22



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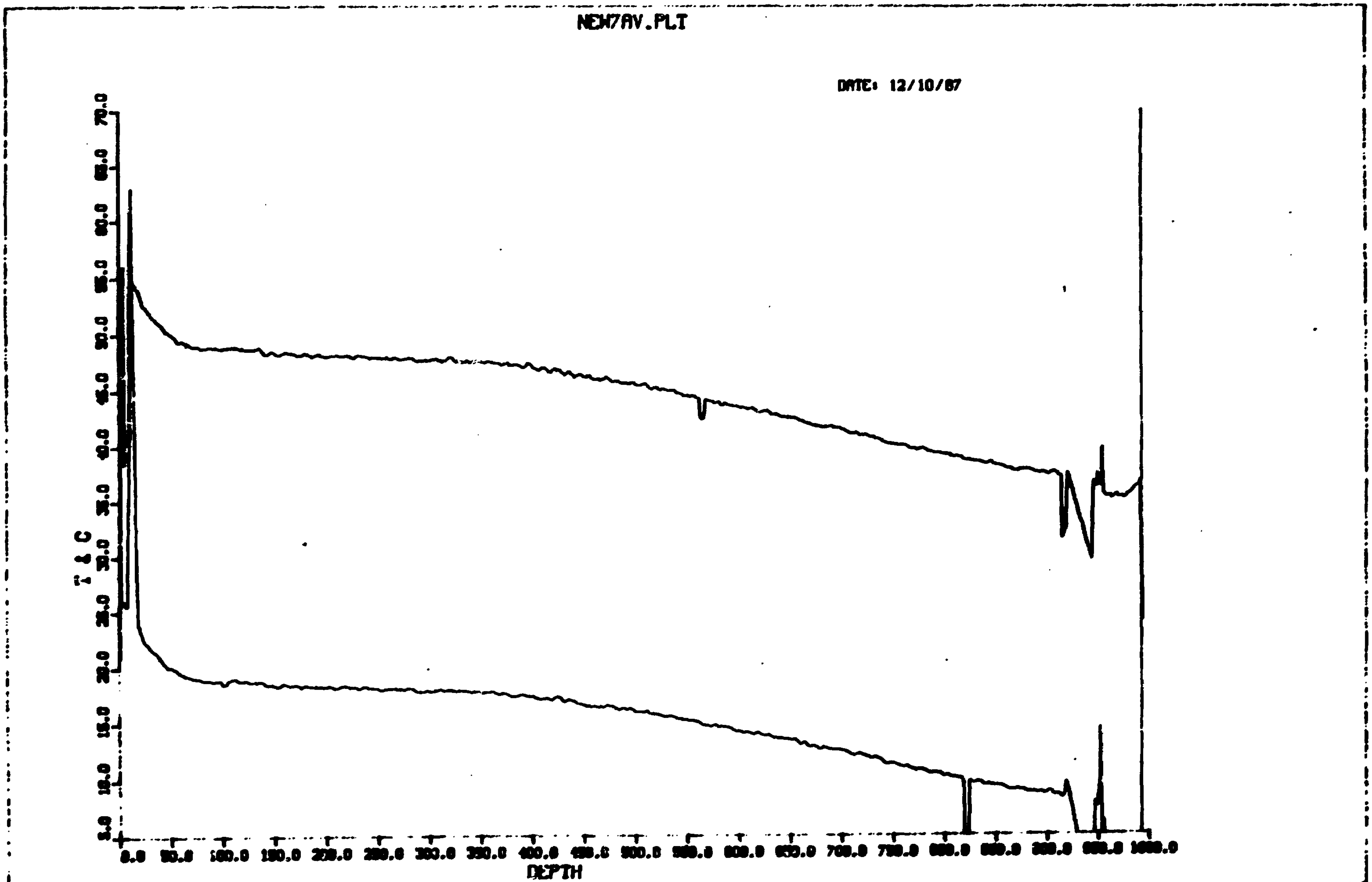

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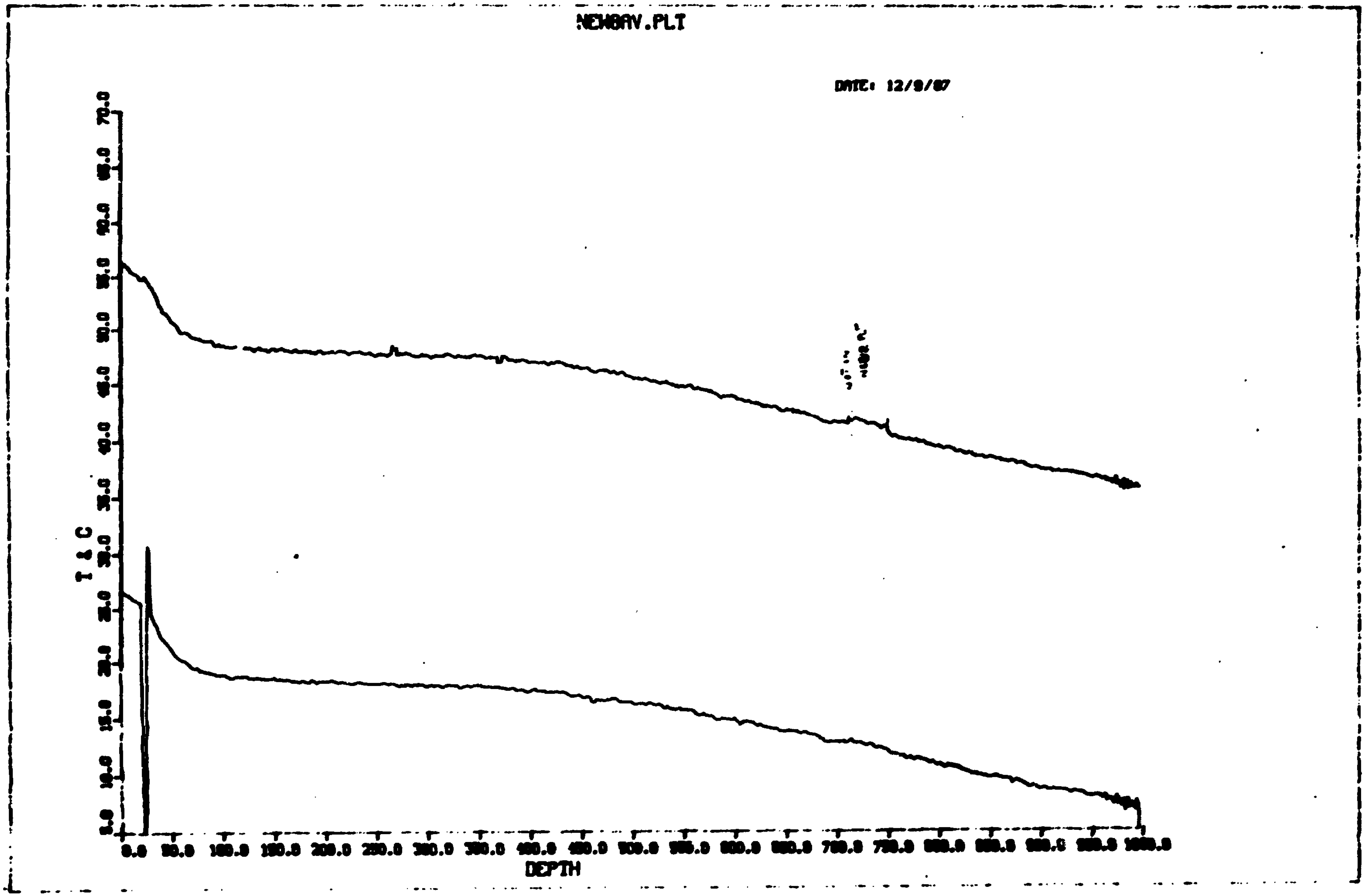

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T & C
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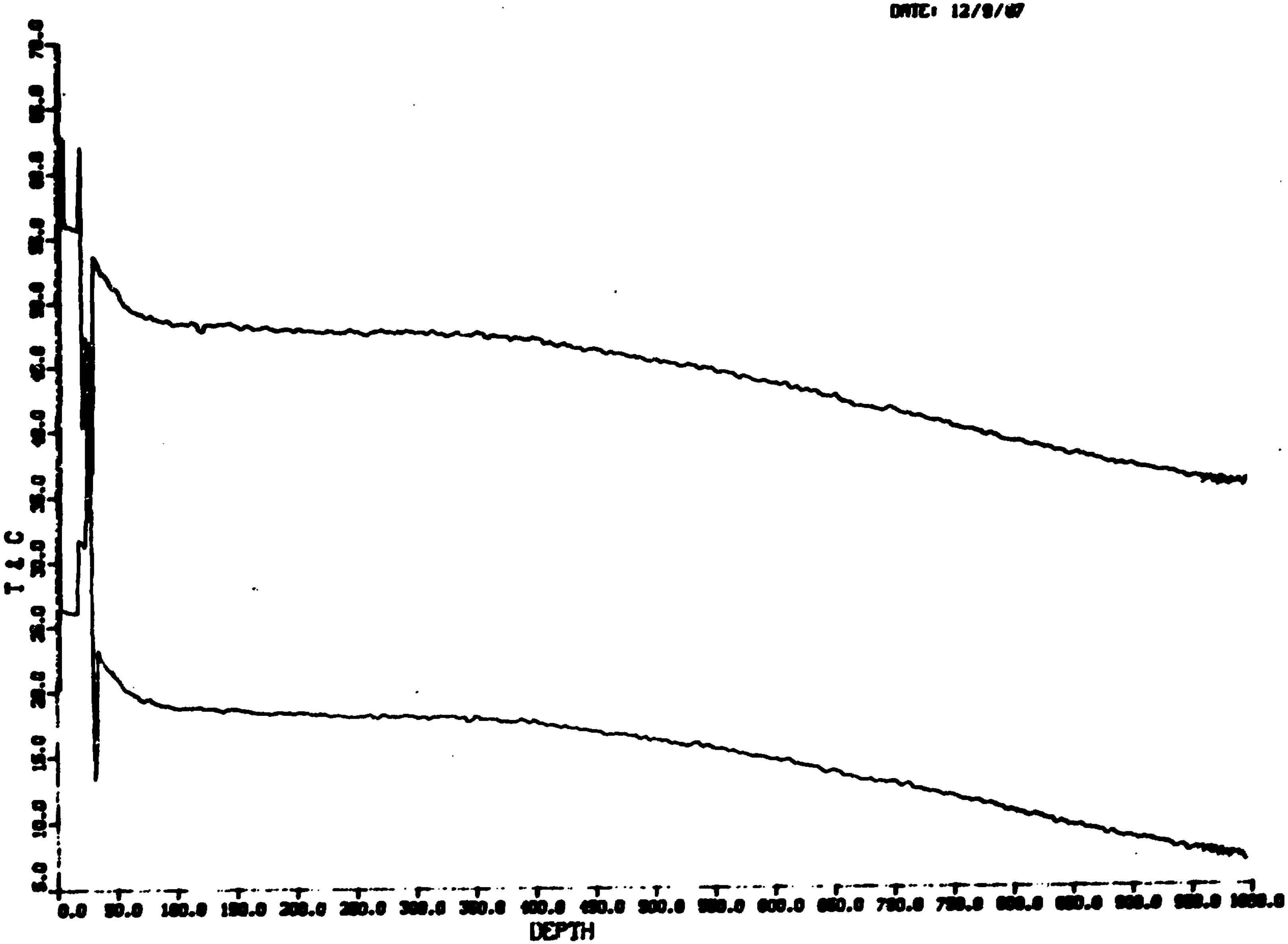

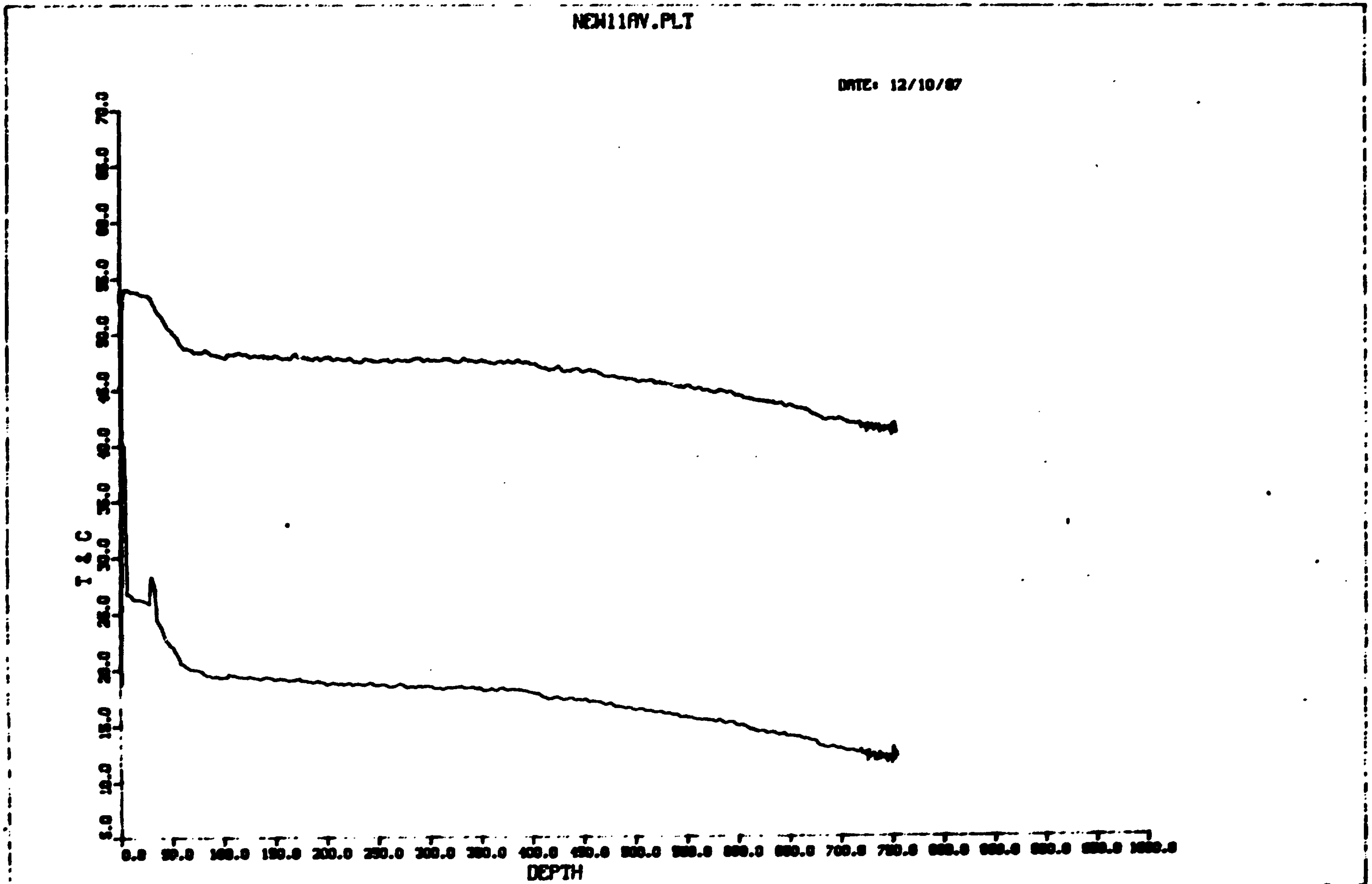
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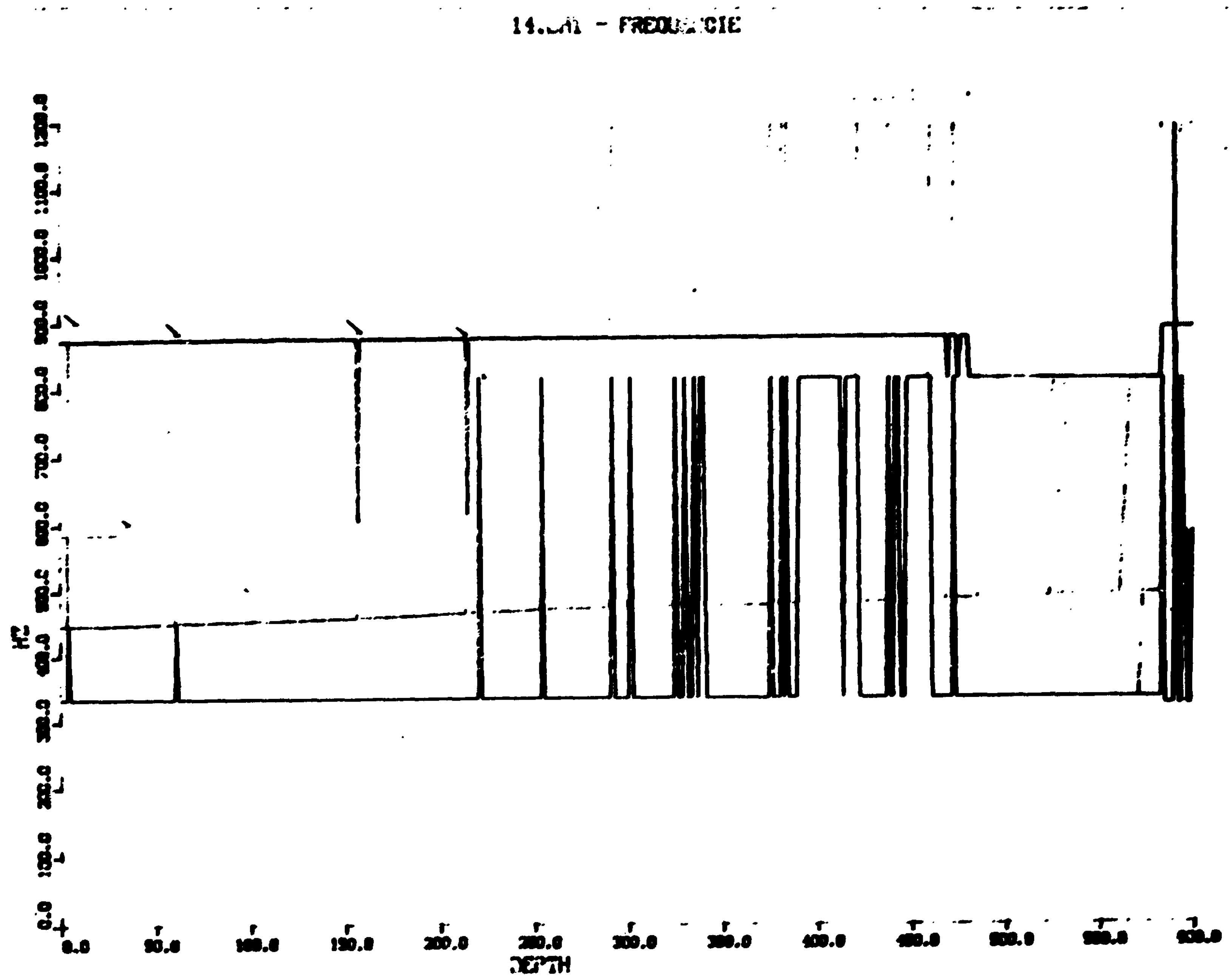
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Fig. 29

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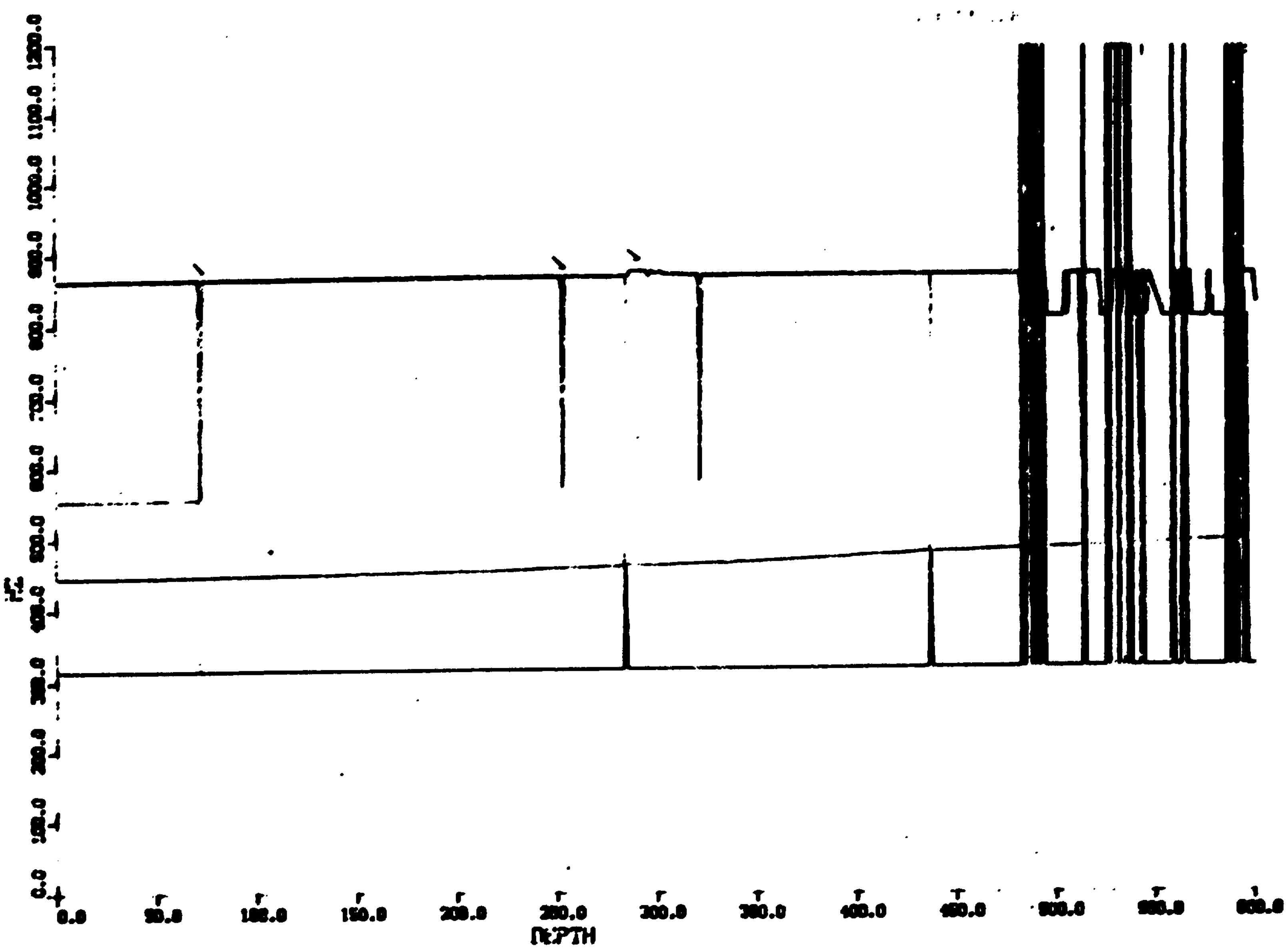

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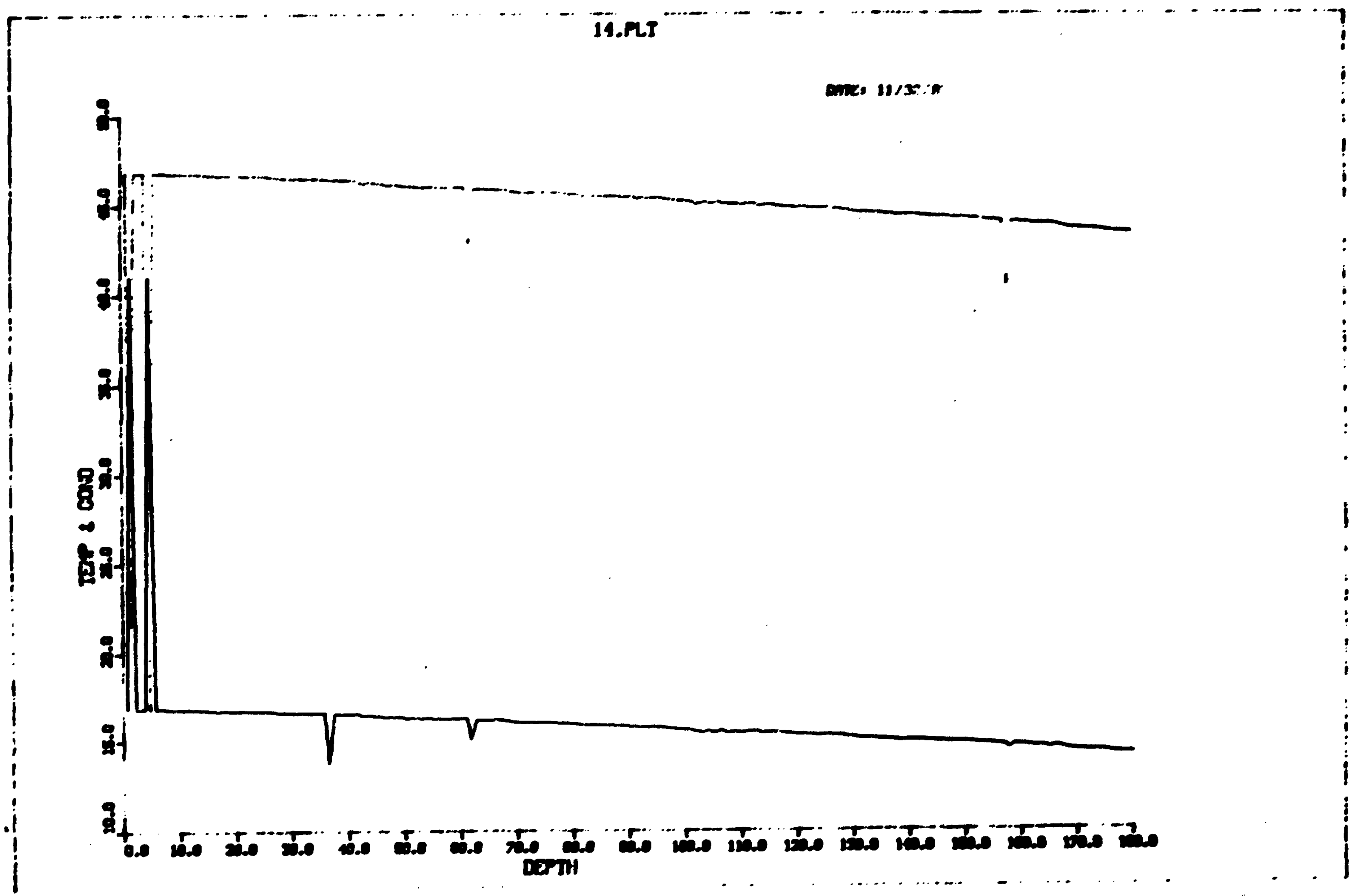
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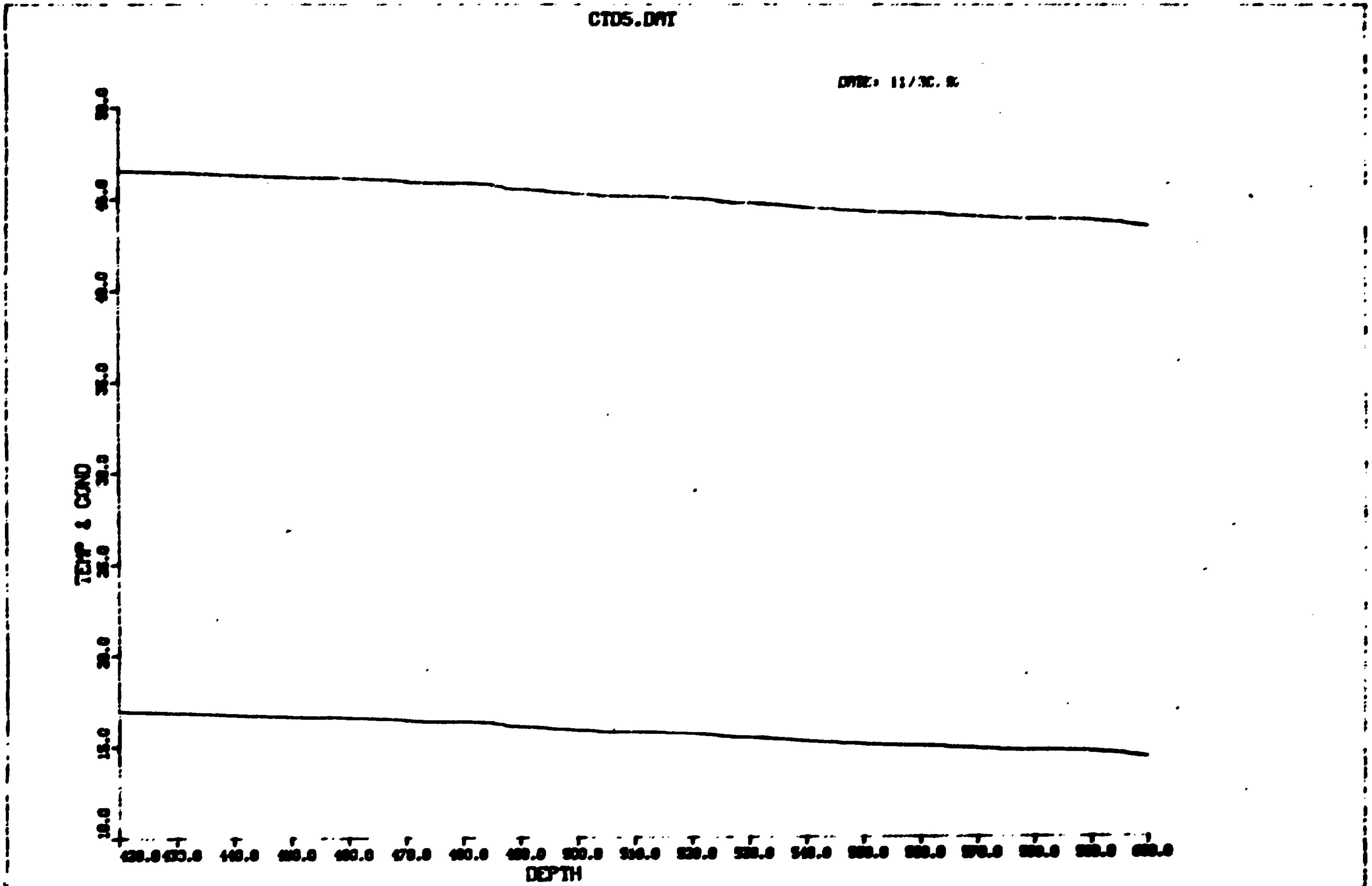
DEPTH

Fig. 30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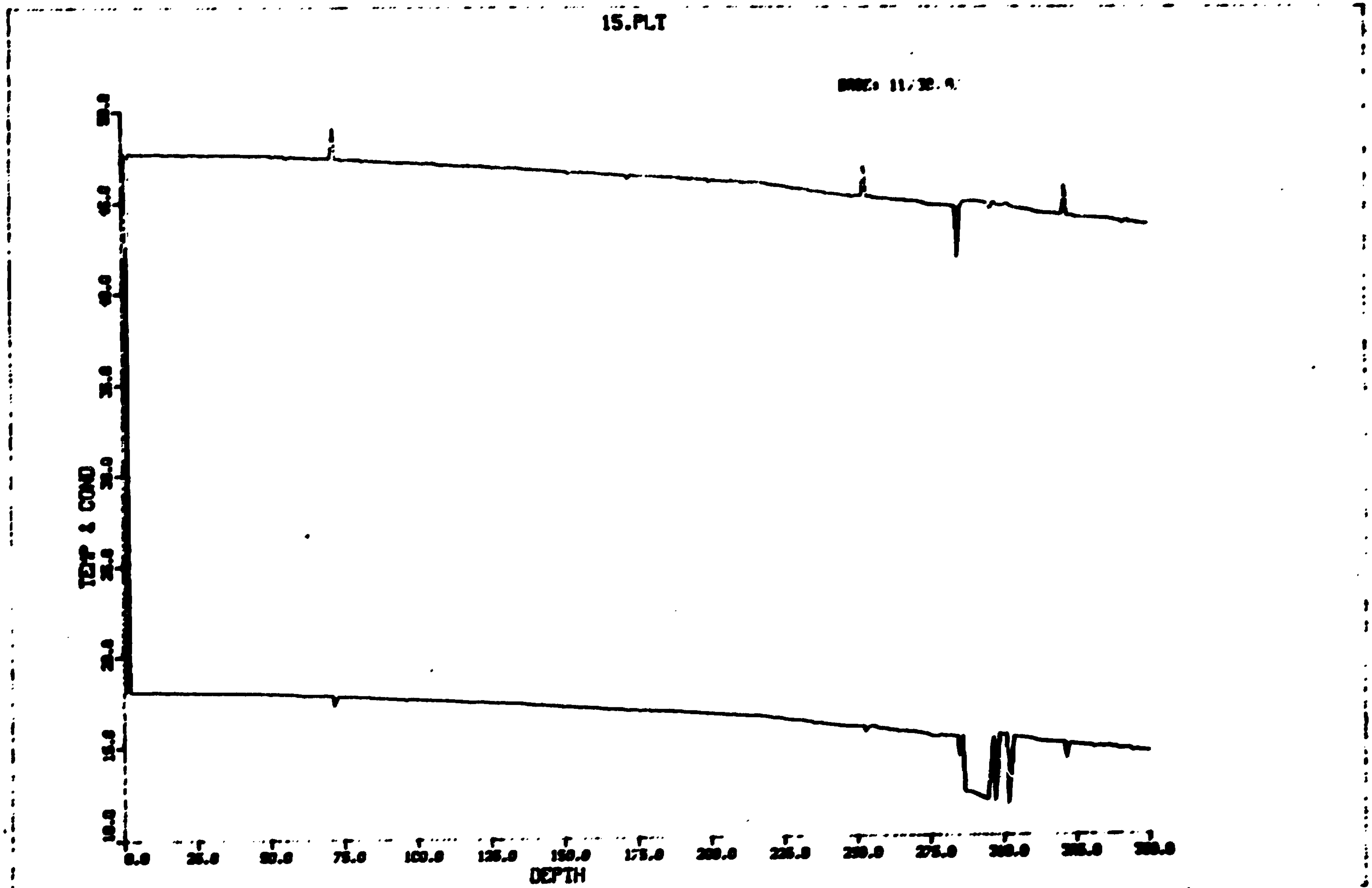
TEMP & COND
DEPTH

Fig 3



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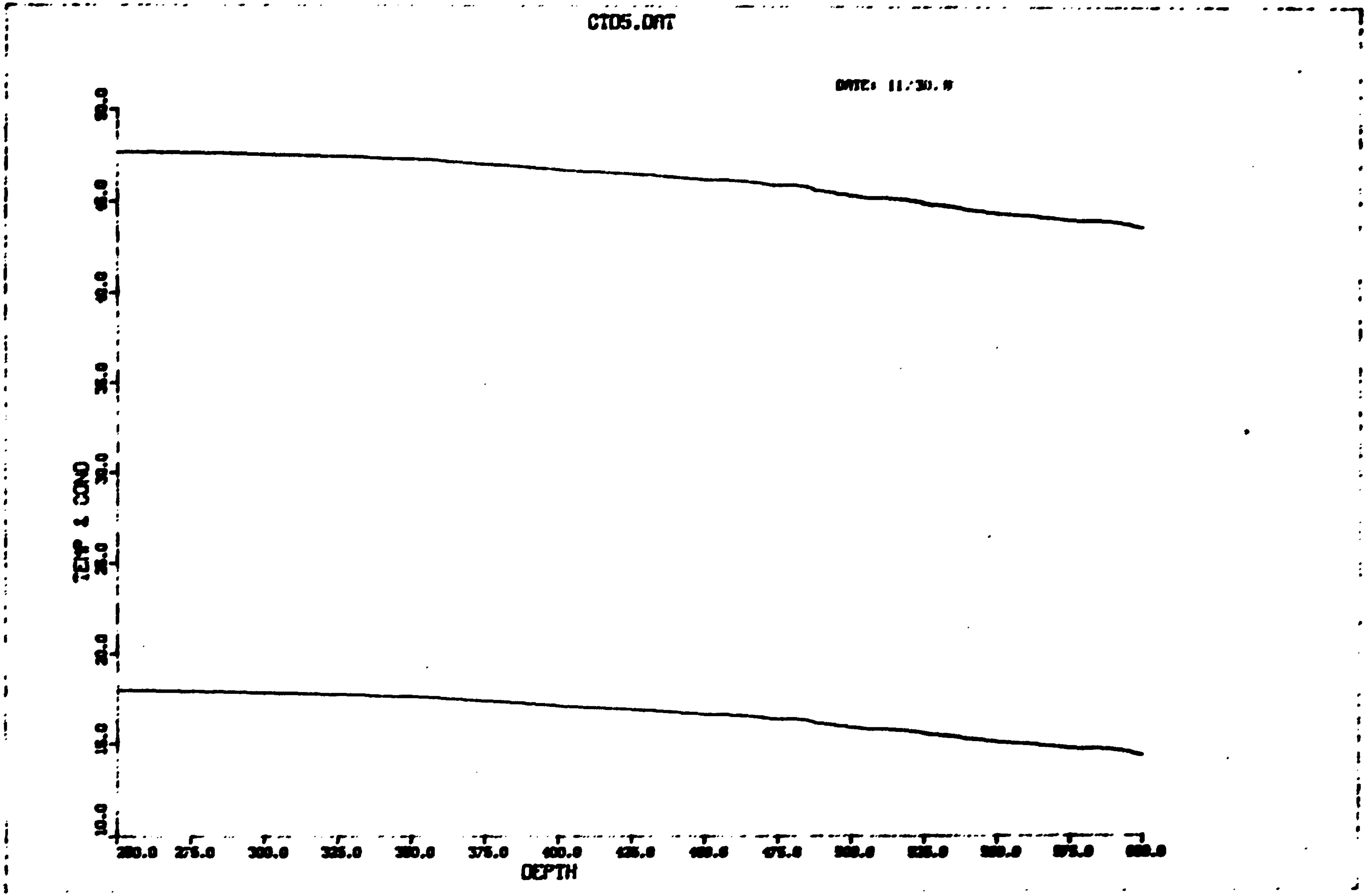
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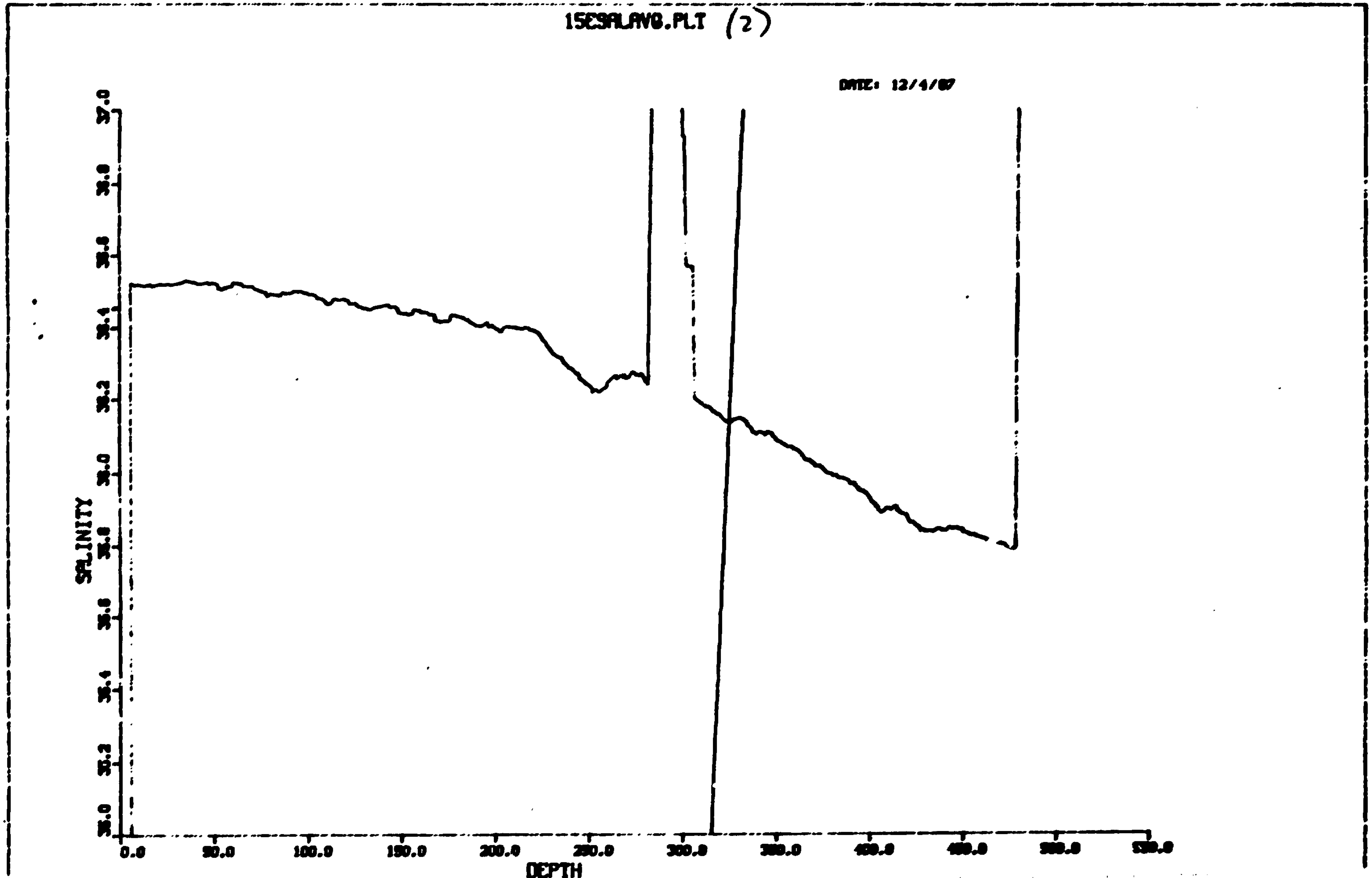
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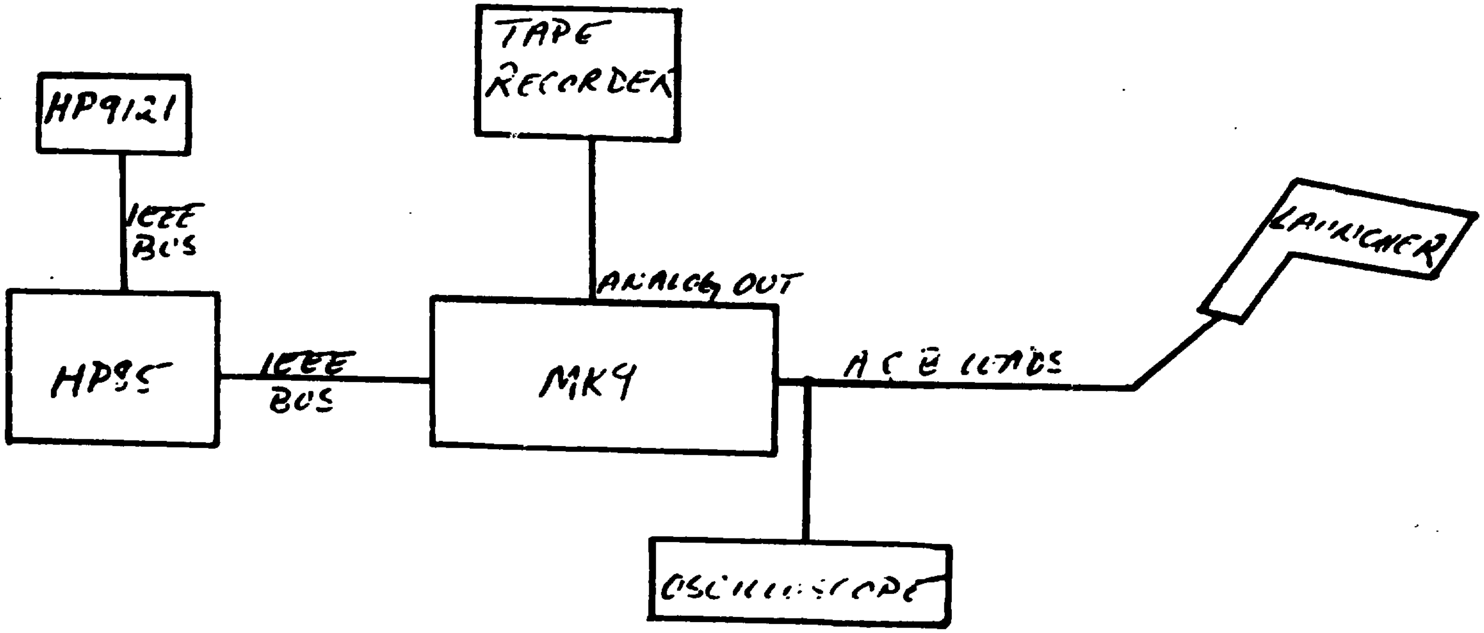

DECK GEAR SET UP FOR XCTD TESTING

APPENDIX C

XCTD SENSORS RESPONSE CHARACTERIZATION

M.B. Manning, B. Dalton, and R.W. Lancaster

Sippican, Inc.
Marion, MA USA

Experiments were performed at the NAVOCEANO Lab in Bay St. Louis, MS, to study the sensor step responses of the XCTD (conductivity cell flushing length, in particular). These experiments were the first of their kind on the Sippican XCTD and were exploratory in nature. A quantitative characterization of the interfaces generated at the NAVOCEANO drop test facility, a measurement of the temperature response time constant and an estimate of the conductivity response time constant of the XCTD were obtained in these tests.

1. INTRODUCTION

The selection of a test facility (1) was predicated upon certain assumptions about the conductivity cell and test apparatus. Since calculations indicated that the flow in the cell was turbulent, a minimum cell travel distance of 4-5 cell lengths (approximately 1m) was necessary to observe the assymptotic approach to full response. Further, reproducibility of the interfaces generated for the test on the length scale of the cell (20 cm) was desirable in order to explore the fine scale measurement potential of the instrument. Experimental artifacts such as the viscous dragging of "old" water into "new" water by the tubing and features of the drop fixture were believed to be non-negligible but tractable. In addition, it was not possible to include cell rotation in the tests at this time. Before the Sippican tests the viscous effects mentioned above and the quality of interfaces developed at the NAVOCEANO facility had not been quantitively studied by a suitable precision probe such as a needle probe.

2. APPARATUS

Below is a diagram of the drop test apparatus at the NAVOCEANO facility (Fig. 1). The key features which were important for the present experiments are the o-ring sealed piston in the tube where the XCTD was positioned and the fixture itself, with the XCTD probe rigidly attached, which is driven through the interface by weights. For an ideal noviscous fluid the probe would be accelerated as the drop fixture fell and the interface would remain unaffected and stable with no mixing of the different water masses due to the falling action. This situation would be maintained until the o-ring sealed piston separates from the tube, at which time the "old" water, initially present in the tube, would flood downward in the tube displacing the recently introduced "new" water. Viscous effects due to several mechanical actions introduce mixing and disruption of the interface to an extent which was initially unknown.

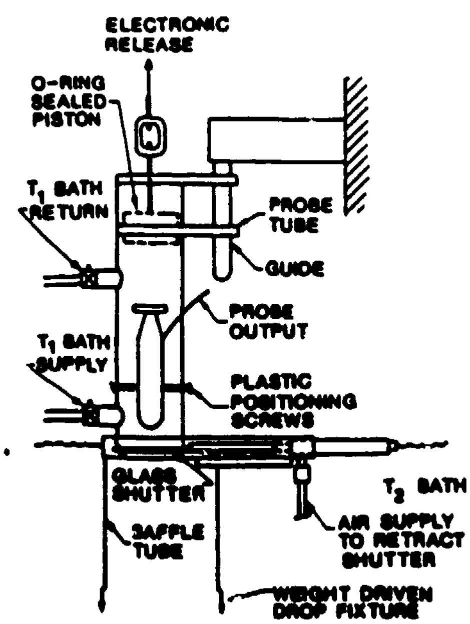

Figure 1: NAVOCEANO water to water drop test fixture for XCTD response characterization study

CH2498-4/87/0000- 216 $1.00 ©1987 IEEE

The Expendable Conductivity, Temperature, and Depth (XCTD) probe is designed to measure the electrical conductivity and temperature via on-probe sensors. Depth is computed from measurements of the time of fall at a known drop rate. A known electrical current is caused to pass through the conductivity cell and the thermistor; the voltage developed across these sensors is directly proportional to the resistance of the sensors. From the resistance measurements the electrical conductivity (from the known cell constant) and temperature (using the Steinhart-Hart equation) of the ocean may be calculated.

The sensors are sampled serially, with fixed calibration resistors sampled between the temperature and conductivity sensors. The resistance data are converted to frequencies which are driven up the expendable wire link for further processing at the surface, typically with the Sippican MK9 and HP85 computer.

For the present study the XCTD probe was altered in order to continuously read out temperature and conductivity data. A Seabird needle probe was used to characterize the interfaces quantitatively during the falling action of the drop test fixture. The Seabird probe had been altered so that the high frequency filter was disabled. These data were recorded on a dynamic signal analyzer (HP 3562A). A software program was used to low-pass filter the original data corresponding to a 5 cm wavelength cut-off.

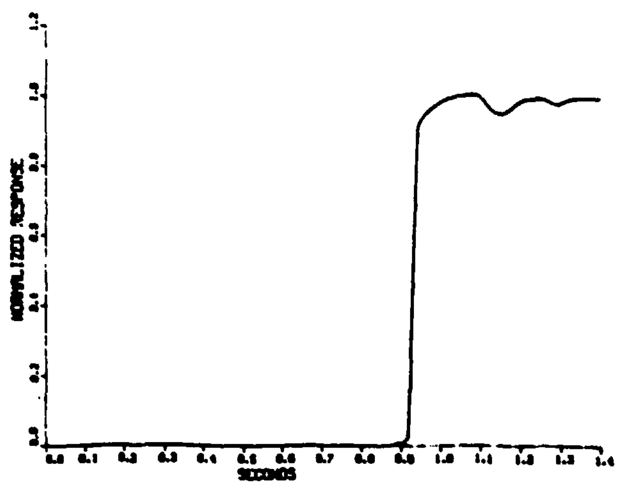

Figure 2: Needle probe trace (reference) of conductivity step interface

3. INTERFACE

The Seabird needle probe was used to profile the interfaces at various drop rates . A characteristic interface trace is shown below in figure 2. A two-step increase may be identified here: an initial sharp rise followed by a gradual rise to a constant level. The gradual rise is believed to be due to the dragging of "old" water by the fixture into "new" water. That is, there is a flushing of the drop fixture tubing itself superimposed upon the cell flushing. This puts some limits on our ability to interpret the full conductivity response condition (99.9%), especially for the conductivity sensor. Nevertheless, the interfaces appear in our data to be reproducible on at least a 10 cm length scale regardless of the drop rate of the test fixture.

The apparent oscillations in the later stages of the recorded signal are due to small drop test fixture motions in the vertical direction subsequent to the drop.

4. XCTD RESPONSE

Figure 3 displays the temperature response of the cell to an interface ($T = 22$ C; $\Delta T = 3.3$ C; $S = 3.5\%$) at 2.7 m/sec. The curve shows a leveling off which we interpret to be the full temperature response of the probe. Because of experimental constraints such as the necessity of initially thermally isolating the drop fixture with the probe attached, it proved impractical to establish the full response of the XCTD by letting the probe come to equilibrium with the "new" water either before or after every drop. Allowing the probe to record in the "new" water before a drop was tried once with the result that the above criterion for establishing the point of complete response was verified. The limit on this check was our ability to reliably correct for a bath temperature drift.

Other features of the data presented in figure 3 are noteworthy. An abrupt reduction occurs after the full signal level is reached in the temperature response. Thereafter a slow recovery toward the higher level occurs but never is reached completely within the available experimental time. This we interpret, as is justified by the distances implied in this time series data, as the flooding of the probe from the rear by "old" water after the o-ring sealed piston separates from the tube at the end of the drop. A gradual rise step, as seen in the needle probe profile, is not present in the figure 3 curve. This may be understood by the fact that the thermistor is a highly localized sensor, not spatially extended like a conductivity sensor, and therefore does not sense the "old" water which has been dragged along by the drop test fixture. Based on this data we measure a time constant of 90 ms for the temperature response.

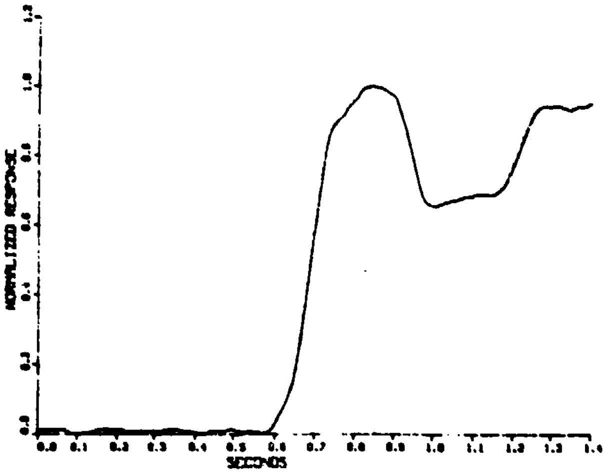

Figure 3: Temperature response of XCTD probe

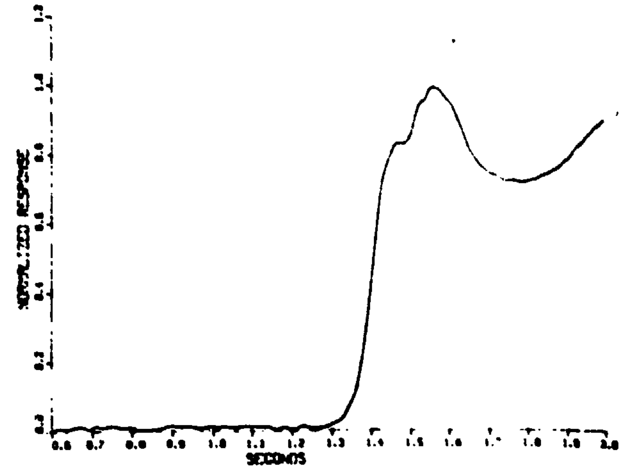

Figure 4: Conductivity response of XCTD probe

For the conductivity response, a more complicated picture appears. Since the cell should sense the conductivity of the water outside the probe (2), we believe that a gradual slope such as was seen by the needle probe should be seen and indeed it is (figure 4). Note also the inflection point in the sharp rise portion of the step response is present as is expected for an extended sensor such as the conductivity cell (2,3). Full response is difficult to demonstrate here however, because of the gradual rise in the conductivity profile as indicated by the needle probe drop. As in the case of the temperature response, the later flooding of the probe by the "old" water after the o-ring sealed piston is removed causes a sharp fall-off in the recorded response which apparently occurs near the end of the gradual rise portion of the conductivity profile. We take the full response of the XCTD conductivity signal to occur at the maximum level reached just before the reduction due to the flooding by the "old" water. This identification is consistent with the needle probe results in that the increase of the gradual slope part in proportion to the total change observed in the needle probe drops is approximately the same at this point in the XCTD drops. A conductivity response time constant estimate is 100 ms.

Relative to the stated conductivity resolution of the XCTD (approximately 0.1% full scale), the present data may be used to estimate a range for the cell flusing length of 80 - 160 cm. The experimental fall rate (240 cm/sec) is significantly less than the actual XCTD probe fall rate (366 cm/sec) implying that the above range formally overestimates the probe flushing length under operating conditions. The XCTD resolution should therefore be sampling rate limited at the present time. Data correction according to a cell transfer function is not required.

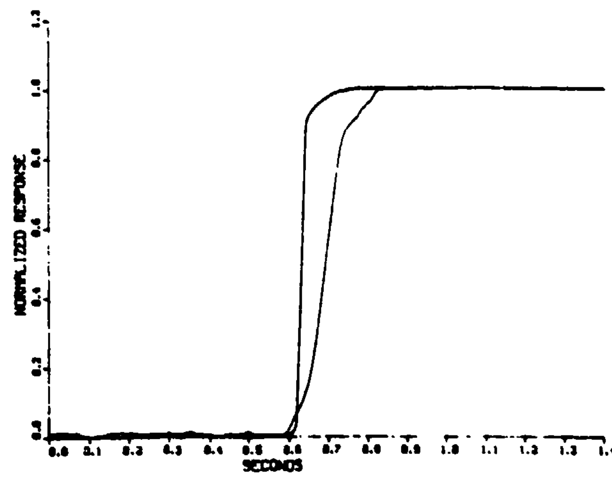

Figure 5: XCTD probe and needle probe conductivity response comparison displaying indicated relative position and long length scale assumptions

The present conductivity results, consistent with the indicated assumptions, are depicted in figure 5 for illustrative purposes.

5. CONCLUSION

The temperature and time constants of the XCTD probe have been measured for the first time. An analysis is given which indicates that the XCTD resolution is sampling rate limited at the present time. Remaining ambiguity in the conductivity cell flushing length determination may be resolved by an experimental arrangement with a longer transit length for the probe with a corresponding extension of the o-ring sealed piston excursion. A higher drop rate (3.65 m/sec) and the inclusion of the probe rotation would be desirable. These extensions of the present work are probably not possible at the NAVOCEANO lab. A suitable alternative facility has not been located.

It is possible to extend the present work to include different sized temperature steps and different temperature ranges. Synchronizing the 3 data channels in order to obtain phase information about the response function is possible within the present design of the NAVOCEANO drop test fixture, although some increase in the tubing diameter of the drop-test fixture would be necessary.

6. ACKNOWLEDGEMENTS

The assistance of Dale McCarty, Pete and Lisa Lessing, Ed Gent and Carlos Mayoral of NAVOCEANO in the performance of these experiments is gratefully acknowledged.

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2. M.C. Gregg, J.C. Schedvin, W.C. Hess and T.B. Meagher, "Dynamic Response Calibration of the Neil Brown Conductivity Cell". J. Phys. Ocean. 12, 720 (1982).

3. F.M. Fozdar, G.J. Parker, and J. Imberger, "Matching Temperature and Sensor Response Characteristics". J. Phys. Ocean. 15, 1557 (1985).